MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

506250

VOL. XCVIII.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

LONDON:
Published by the Institution,
25, GREAT GEORGE STREET, WESTMINSTER, S.W.
[TELEGRAMS, "INSTITUTION, LONDON." TELEPHONE, "3051."]
1889.

[*The right of Publication and of Translation is reserved.*]

ADVERTISEMENT.

The Institution as a body is not responsible either for the statements made, or for the opinions expressed, in the following pages.

LONDON: PRINTED BY WM. CLOWES AND SONS, LIMITED, STAMFORD STREET AND CHARING CROSS.

CONTENTS.

SECT. I.—MINUTES OF PROCEEDINGS.

9, 16, and 30 *April*, 1889.

PAGE
"Armour for Ships." By Sir NATHANIEL BARNABY, K.C.B. (8 cuts) . . 1
Discussion on ditto 25
Correspondence on ditto 75

23 *April*, 1889

No meeting, it being Easter Tuesday 81

7, 14 and 21 *May*, 1889.

Transfer of Associate Members to class of Members 82
Admission of Students 82
Election of Members and Associate Members 82
"The Treatment of Steel by Hydraulic Pressure, and the Plant employed for the purpose." By W. H. GREENWOOD (1 plate, 11 cuts) . . . 83
Appendixes to ditto 133
Discussion on ditto. (3 cuts.) 145
Correspondence on ditto 193
Announcement by the President of the death of Mr. Francis Croughton Stileman, Member of Council 203
Transfer of Associate Members to class of Members 204
Admission of Students 204
Election of Honorary Members and Associate Members 204

28 *May*, 1889.

Annual General Meeting: Election of Council 205
Report of the Council, Session 1888–89 207
Abstract of Receipts and Expenditure from 1 April, 1888, to 31 March, 1889 220

PAGE
Premiums awarded, Session 1888–89 224
Subjects for Papers, Session 1889–90 226
List of Original Communications received, and of Donors to the Library, from 1 April, 1888, to 31 March, 1889 231
List of Paintings in the Possession of The Institution of Civil Engineers, September, 1889 248
List of Officers, 1889–1890 249

SECT. II.—OTHER SELECTED PAPERS.

"Experiments on a Steam-Engine, the Cylinder of which was heated externally by Gas-flames." By B. DONKIN, Jun. 250
"Investigation of the Heat-Expenditure in Steam-Engines, especially with reference to Methods of Diminishing Cylinder-Condensation." By Professor V. A. E. DWELSHAUVERS DERY. Translated by Professor W. C. UNWIN. (1 plate) 254
"The Improvement of the River Avon below Bristol." By W. CHATHAM. (2 plates) 280
Appendix to ditto 291
"Flexible Wheel-bases of Railway Rolling-Stock." By J. D. TWINBERROW. (6 cuts) 292
"Experiments on the Strain in the Outer Layers of Cast-Iron and Steel Beams." By E. C. DE SEGUNDO. (1 plate, 8 cuts) 308
Appendix to ditto. (3 cuts) 333
"The Cyclical Velocity-Variations of Steam and other Engines." By H. B. RANSOM. (1 plate, 3 cuts) 357
"Balanced Slide-Valves" By J, C. PARK. (1 plate) 369
"Underpinning Great Yarmouth Town Hall." By F. E. DUCKHAM. (1 plate) 372
"On the New Programme for Ship-building." By W. H. WHITE. (1 plate) 375
Obituary: 387
George Henry Bayly, 387; William Brown Clegram, 388; James Farrar, 390; Sir Charles Lanyon, 391; Henry Peveril Le Mesurier, 393; Frederick Leslie, 397; The Hon. Henry Haworth Leslie, 398; Charles Reboul Sacré, 399; James Simpson, 400; Francis Croughton Stileman, 401; Frank Charles Black, 402; William Arthur Frend, 403; Samuel Petty Leather, 404; Staff-Commander William Walter Kiddle, R.N., 405; John Phanuel Roe, 405; Colonel Hamilton Tovey, 408.

SECT. III.—ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

PAGE

Note on Tensile Tests of Metal. P. ARNOULD 412

The Influence of Temperature on the Mechanical Properties of Metal. A. LE CHATELIER 413

Permeability of Cements and Cement-Mortars under Pressure. L. M. HAUPT 414

The Manufacture and Properties of the Cements of the Isère. A. GOBIN . 415

The Manufacture of Slag-Cement. J. GROSCLAUDE 419

Utilization of Waste Products 421

The Renewal and Reconstruction of Iron Bridges in Austria. LUDWIG HUSS 422

Viaduct over the Adda at Paderno. G. SACHERI 424

The Moldau Viaduct at Cervena. L. HUSS 426

A New system of Examination for Iron Bridges. F. LARROQUE . . . 427

An Apparatus for the Measurement of Strains in Ironwork. J. DEISTLER. 428

The Extension and Improvement of Libau Harbour 429

The Port of Nicolaieff. D. GNUSIN 430

Progress of the Works of Improvement in the Bilbao River 431

The Peculiarities in the Wear of Paving Setts. — FICHTNER 433

Wave-power Pump 434

Duty-Trials of Pumping-Engines. GEORGE H BARRUS 434

Godillot's Step-grate Furnace for Burning Poor Fuels. — BRÜLL . . . 438

Water and its Cost. — KINDERMANN 439

Wiener-Neustadt Water-Supply 440

The Water-Supply of Tôkiô. A. SCHWARZ 441

The Influence of Ventilation on the Micro-Organisms in Suspension in the Atmosphere. Dr. RICHARD STERN 442

The Physical Action of Precipitants upon Micro-Organisms present in Water. BRUNO KRUGER 443

The Employment of Carbonic-Acid Gas for the Determination of the Air-Renewal in Inclosed Spaces. Dr. R. J. PETRI 445

The Disinfecting Properties of Creosote Dr. CARL FRANKEL 446

Experiments on the practical Disinfection of Excrementitious Substances. Dr. S. VON GERLÓCZY. 447

The Dessendier Recording Photometer. A. PALAZ 449

Railway from Ciaño-Santa Ana to Soto del Rey 450

Railway from Zafra to Huelva 451

The Kaiping-Tientsin Railway in China. ADOLF SCHWARZ 452

Projected International Railway through the Centre of the Pyrenean Range. J. M. DALMAN 453

Consumption of Railway Sleepers in France. H. MATHIEU 454

On the Duration of Steel Rails. — COÜARD 456

The New Rail of the Paris Lyons and Mediterranean Railway. J. MICHEL 457

The Use of Flangeless Wheels in the Middle of Six-wheel Trucks . . . 458

Experiments with the new Quick-Acting Westinghouse Brake on the Baden State Railway. — EMMERICH 459

Koyl's Parabolic Semaphore 460

The Tramways of Madrid 461

PAGE
Shallow-Draught Screw-Steamer 461
Turret Barbette on the Canet System for 12·6-inch guns. 462
An Exposition of the Mode in which Water is affected by a body moving in it. B. F. Isherwood 463
Experiments on the Removal of Mine-Gas by Exhaustion. H. Brenner . 464
Report upon the Coal-Deposits in the Indwe Basin and Stormberg Range of Mountains. W. Galloway 466
Maliwun Tin Mines (Mergui District) 468
Report on the Oil-Fields of Twingoung and Beme, Burma. Dr. Fritz Noetlong 469
Magnetic-Iron-Ore Mountains of North Sweden and the Ural. — von Schwarze 472
The Arroyo Seco Gravel (Gold) Mine 474
Method of Treating Gold Ore at Deloro, Canada. J. E. Rothwell . . 476
The Smelting of Gold and Silver Ores at Argo, Colorado. R. Pearce . 477
The Development and Present Condition of Puddling in Gas-Furnaces. E. Goedicke 480
Basic Steel and the Canalization of the Moselle. A. Oelwein 483
Barrel Chlorination. A. Thies 484
A General Law of Induction in a Circuit devoid of Resistance. G. Lippmann 485
Experiments on the Practical Values of Galvanic Batteries. K. Sosnovsky 485
The Brush Electric Company's new Alternating-Current System . . . 487
A Rotary Commutator for Induced Currents. P. le Goaziou 488
Economical Size of Line-Wire for Constant-Current Circuits. — Rhodes 489
Measurements of the Insulation of Porcelain Insulators. — Schomburg . 490
The Suppression, in a special instance, of the Difficulties from Induction and Leakage between neighbouring Telephone Wires. E. Massin . . 490
An Experimental Theory of Lead Accumulators. Gaston Roux . . . 491
The Consumption of Energy in Electro-Metallurgical Processes. H. Ponthière 492
Index. 495

CORRIGENDA.

Vol. xciii., p. 236. The scale of the Fig. of Mr. Willans' engine, instead of being 3 inches = to 1 foot, should be one-twentieth full size.
„ xcvii., p. 424, line 3, *for* "1886" *read* "1866."
„ „ p. 495, line 10 from bottom, *for* "2 feet" *read* "2 inches."

THE
INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1888-89.—PART IV.

SECT. I.—MINUTES OF PROCEEDINGS.

9 April, 1889.
SIR GEORGE B. BRUCE, President,
in the Chair.

(*Paper No. 2399.*)

"Armour for Ships."

By SIR NATHANIEL BARNABY, K.C.B.

ITS USES AND ITS NATURE.

AT the commencement of the Russian War in 1853-4, several points in relation to the defence of ships against projectiles had been established, by experiment, to the full satisfaction of the naval experts. It had been settled that war-ships must be built of wood; iron was an altogether unsuitable material, as the captain of H.M.S. "Excellent" reported in 1850, that "whether iron vessels are of a slight or substantial construction, iron is not a material calculated for ships of war." Seventeen iron ships, which had been in process of construction for fighting purposes, were thereupon condemned as useless for war-service. It had been decided that protection by armour-plates was of no value. Iron plates 6 inches thick placed in front of the wood had failed to protect it. Admiral Sir Thomas Hastings had reported that wrought-iron plates (6 inches thick) riveted together, and fixed over the planking of a ship's side, would give no protection at 400 yards against shot fired, with 10-lb. charges from 8-inch guns, and from heavy 32-pounders. The favourite guns were therefore shell-guns.

The armament of a three-decker of 121 guns consisted of one-half of 65-cwt. shell-guns, and one-half of 32-pounders, with one 68-pounder pivot-gun. The shell-guns were placed on the lower and middle decks. In a two-decked ship the lower deck was armed throughout with shell-guns, and the other decks with 32-pounders of from 42 to 58 cwt. In some cases the main deck was partially armed with shell-guns. The frigates were armed with 8-inch 65-cwt. shell-guns on the main deck, and with 32-pounders on the upper deck. All shot were of cast-iron. No one knew what the result of an action with these shell-guns would be, but all agreed that the struggle would be short.

In the autumn of 1853 a Turkish fleet, of seven frigates and some smaller vessels, was attacked at Sinope by a Russian fleet of six line-of-battle ships (three of them first-rates), two frigates, and two or three smaller vessels. The Turkish ships had no shell-guns. They were armed with 24-pounder shot-guns. In less than five minutes a Russian ship of the line, "Grand Duke Constantine," destroyed a battery and a Turkish frigate anchored near it, chiefly by shells from the lower deck. A short time afterwards, the "Ville-de-Paris," another Russian ship of the line, blew up, by shells, another Turkish frigate. Of the crews in the Turkish fleet above three thousand perished. Of the ships only one small steamer escaped.

In the allied attack upon the forts at Sebastopol in October, 1854, the "Agamemnon," "London," "Sans Pareil," and "Albion," took up positions within 1000 yards of Fort Constantine, which was armed with one hundred and four of the heaviest guns, and was supported by three other smaller heavily armed batteries. In about an hour the "Albion," "London," and "Sans Pareil," were so injured that they had to haul off to a greater distance. The "Sans Pareil" and "London" soon afterwards resumed their stations to support the "Agamemnon." The "Rodney," "Queen," "Bellerophon," and "Arethusa," also came to her support. The "Queen" was almost immediately set on fire by a shell, and had to be towed out of action. The "Agamemnon," and the remaining vessels, kept up the cannonade, which had commenced at two o'clock P.M., until it was dark, when they drew off. They had in all three hundred and ten men killed and wounded. The "Albion" and "Arethusa" were so damaged that they had to be sent to Malta for repairs. The "Albion," "Retribution," "London," and "Queen," had all been on fire, chiefly from the effects of shells with time fuzes.

The destructive effect of the shells, and other incendiary projectiles used by the Russians in these engagements, led to the immediate use of armour, notwithstanding the previous adverse decisions of English gunnery officers. The adoption of armour led at once to the use of iron in the hull by English architects, in spite of the series of experiments at Portsmouth, which have been referred to, and which had brought about the condemnation of the fleet of seventeen iron ships.

The first move in the direction of armour-plating was made by the French, in the month succeeding the unsuccessful attack of the allied fleets upon Sebastopol. In an Imperial order to the French Minister of Marine, dated from St. Cloud, 16th November, 1854, the Emperor Napoleon III. pointed out that in warfare there must be, in addition to courage and ability, even chances. Actions on land are avoided so long as there is no chance of success. So in naval warfare, if the fleet were risked, it would be in the hope of destroying that of the enemy. An enormous capital is hazarded in order to destroy that which has cost the enemy as much. But, he went on to say, so soon as the fleet is employed in the attack of a fortification the proportions are entirely altered, for not only will a ship be found inferior to a land battery, because a ship offers a large object to strike, while the land battery occupies but little space, and is protected by parapets, but also the stake is materially different. So it happened that in the Black Sea twenty-five thousand sailors and three thousand guns could not seriously injure the Russian fortifications; and that indecisive attacks were made at other places, entailing serious damage to the ships without doing any material harm to the enemy. Under the existing conditions risks were incurred for nothing. If the ships threw their projectiles at 2,000 metres, they consumed their ammunition at a dead loss and gave a false idea of the power of the fleet. If they approached nearer, they exposed the State to sacrifices too considerable in proportion to the object in view, for it would generally be perfectly senseless to risk the loss of a fleet for the destruction of a few forts. To remove this difficulty he proposed to create "*une flotte de siège*," capable of producing decisive effects, and at the same time of lessening to the State the chances of loss in men and money. The course taken to meet the Emperor's views was to build floating batteries with numerous light broadside guns, and covered from end to end with iron armour-plates.

Table I. shows what changes in distribution armour has undergone since 1854.

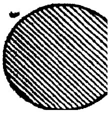
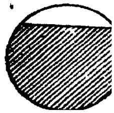
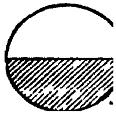
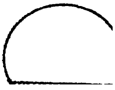
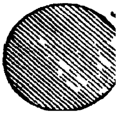
There are two periods. In the first period, the armour was employed, as has been seen, to make the chances of loss of capital more nearly even in a contest between ships and forts. The ships or floating batteries were to be small, numerous, and armoured. In the second period, the armour was to protect sea-going ships in contests with the sea-going ships of an enemy. That period is still current, and has reached a fifth phase, a phase which is in fact only a repetition of the first.

The illustrations have been confined to the ships of the French

TABLE I.—PHASES OF ARMOUR.

1st ***Period.*** ***Floating Batteries.*** **1854–58.**

2nd Period. 1858–1888.

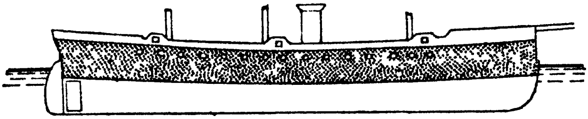
	*Gloire.*	1858. 1st phase	Armour (side) 4¾ inches.	5,500 tons, speed 12¾ knots.	Percentage of weight devoted to armour, 15.
	*Marengo.*	1869. 2nd phase	Armour (side) 7¾ inches.	7,750 tons, speed 13½ knots.	Percentage of weight devoted to armour, 17.
	*Baudin.*	1880 3rd phase	Armour (side, &c) 22 inches.	11,200 tons, speed 15 knots.	Percentage of weight devoted to armour, 33.
	*Tage.*	1886. 4th phase	Armour (deck) 3 inches.	7,000 tons, speed 19 knots.	Percentage of weight devoted to armour, 14.
	*Dupuy de Lôme.*	1888. Return to 1st phase	Armour (side) 4 inches.	6,300 tons, speed 20 knots.	Percentage of weight devoted to armour, 15.

Navy, as the English are in no way responsible for them, and can perhaps, regard them dispassionately.

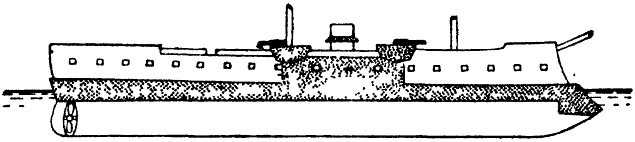
The first phase of the second period was entered upon in 1860, when a sea-going ship, the "Gloire," was launched, clothed from end to end in exposed parts with iron armour. Some of this armour, 4¾ inches thick, was impenetrable to the heaviest guns then carried at sea. The second phase soon followed. It was marked by growth in the weight of the gun, by improvements in the powder, and by alterations in the form and character of the projectile to enable it to perforate armour. It was characterized, on the other hand, by increases in the thickness of the armour, and by improvements in its quality. But the ship did not increase in size. The British sea-going ironclads of the first phase, commenced in 1861, are larger than those in the "Admiral" and "Victoria" classes built twenty-five years later.

To resist growth in the size of the ships for twenty-five years, while the gun and the armour were making strides in advance, was no easy matter. And, while this growth in the gun and the armour went on, torpedoes were introduced and torpedo boats. Higher speeds became thereupon necessary, and had to be given to the ships.

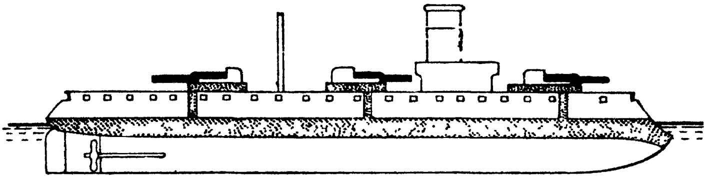
Figs. 1.



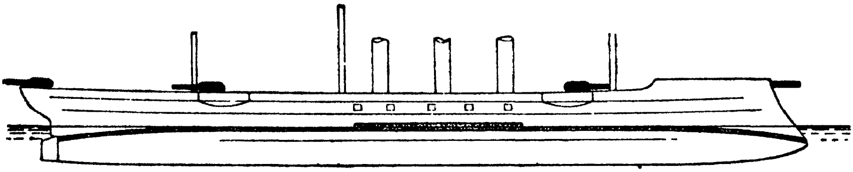
GLOIRE.
5,600 Tons



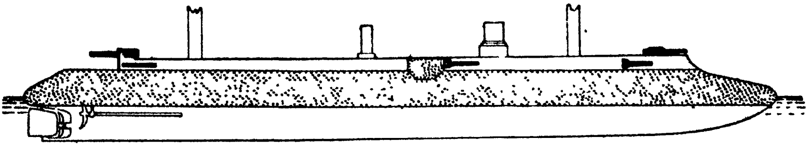
MARENCO.
7,750 Tons.



AMIRAL BAUDIN.
11,200 Tons



TAGE.
7000 Tons.



DUPUY DE LÔME

In the second phase of this second period, the French ships underwent a remarkable change, rendered necessary by the foregoing considerations. The French divided their battery, as the English had already done, into two parts. They continued to protect one part with armour, and the other they left unprotected. The relative extent of these two batteries was subjected to continual modification. The number of guns protected became less and less in succeeding ships, while the number of those left unprotected increased.

At last, taking the "Amiral Baudin" for example, launched in 1883, and the "Formidable" launched in 1885, there are from eight to sixteen machine-guns, and twelve 5½-ton guns fought without armour-cover from any direction. The only guns having any armour protection are three in number, each of 75 tons, and these are protected only as to the carriage of the gun: its breech, its charge, and its loaders are without any armour-cover. The signal stations and the officers in command are also unprotected by armour. Admiral Touchard, the French Controller of the Navy in 1873, gave the reasons for this reduction in armour.

Referring to the "Gloire," "Marengo," "Hercules," and "Kœnig Wilhelm," he says:—

"These, then, are the instruments for fleet-fighting of to-day. Is it to be believed that they will continue to occupy the first position, that they will be the *ne plus ultra*? No, for the gun goes on always increasing in power; and in France, as in England, Russia, and Prussia, we are no longer contented with guns of 10 and 11 inches, we go up to 12 and 13 inches, and there are laid down in the dockyards ships for fleet-fighting, plated with armour from 9½ to 12 inches thick, and from 9,000 to 10,000 tons displacement. Where shall we stop in this strife? Where will it end? I see the end" (he goes on to say) "in the abandonment of armour for the guns Sooner or later this will be the end for the armoured cruising ship. "Let us admit if you will," he says, "that the battery should for the future be plated with armour of 10 inches, as it soon will be, the question of abandoning it will, nevertheless, be resumed upon these two considerations.—1. Is battery armour of 10 inches penetrable? 2 If it is penetrable, does it not become rather a danger than a protection?" And then he goes on to say.—"And now let us see what will take place in a battle between fleets The two squadrons being in order of battle, if both freely accept the contest, there will be collision by ramming, either with or without preliminaries. In any case, it will suffice that one of the two should be resolved for it to make ramming the first act; let us mark the opening phase of the fight. The combatants advancing towards each other would be ranged in one line, or in several lines, or in squadrons; but, whatever be the order of battle, there will be formidable collisions and grinding of the sides; they will cross each other's courses, and then, putting the tiller hard over, will return to the encounter. Again will they strike and again pass on. Woe to the vessel which, disabled by the first attack, or turning less quickly than her adversary, exposes her flank! Like the 'Re d'Italia' at Lissa, she will be sunk by a single blow."

> "It is here—in this initial phase—the ships perpetually fouling each other, that the gun appears on the scene in all its might. The manœuvre is foreseen. A single order, clear, concise, energetic, follows in three words, 'Prepare for ramming.' At this command, the guns are pointed low; the captain of each, his eye fixed on the sights, with bent body and extended arm, waits! He watches the moment when his adversary will pass before the muzzle of his gun—the moment, fleeting as the light, which he must seize for firing. Silent and motionless each man is at his post, but lying full length upon the deck. The captain alone remains erect; suddenly the guns and musketry burst forth, and the vessels crash into each other with their sharp-pointed prows, and gliding by each other prolong the contact along their sides until they reach their sterns, which they avoid in order to protect their rudders and screws. After this first encounter, the combat will always be carried on at a short distance, if not broadside to broadside, the gun and rapidity of evolution playing the principal *rôle*."

At the same date Admiral Sir John Dalrymple Hay, who had been President of the Armour-plate Committee, said:—

> "I come to the conclusion at which Admiral Touchard has arrived, that it is impossible to conceive of any ship but a ship of the very first class, ships of which I do not think many are likely to be constructed, which will be entirely and completely covered with impenetrable armour. If the armour is not impenetrable, then it is worse than useless."

Of the several parts demanding protection he gave the following. with his opinion of the order in which they stood as to importance

1. The magazine.
2. The propelling machinery.
3. The mountings for the heavy guns.
4. The water-line.
5. The men.

The Commander-in-chief at Portsmouth in 1876, Admiral Sir George Elliot, said, in an address circulated among Members of Parliament, that vast sums of money had been uselessly expended in clothing ships with outside armour, because this feature of protection against the gun-attack had not been submitted from time to time to the independent judgment of competent critics. He considered that "the evidence of the superiority of the gun, and the development of the efficacy of the ram and the torpedo had deprived us of sufficient excuse of late years to continue to fight the losing game of armour against guns." He complained that the Admiralty had treated the ram and torpedo attack as secondary, and that its efforts should have been directed toward the protection of ships under the waterline rather than above it.

These French ships, "Amiral Baudin" and "Formidable," mark the close of the third phase of the second period.

The fourth phase in the French Navy, marking the total abandonment of side-armour in fighting ships of considerable size, was not reached until ten years after Admiral Sir George Elliot had declared it to be necessary to abandon side-armour, even in the largest ships, in the terms quoted above. The building of the "Tage" marks this phase. This vessel, called a protected cruiser, is far larger than the fully armoured line of battle ships of 1858, and is armed with sixteen guns, capable of perforating 8 inches to 10 inches of iron armour. Although much larger than the "Conqueror" or "Hero," the only armour is the bomb-proof deck over the machinery and magazines.

Writing, four years ago, an article on ship-building for the "Encyclopædia Britannica," the Author said:—

> "The use of armour has arrested the development of the shell. But it is not inconceivable that its abandonment in front of the long batteries of guns in the French and Italian ships will invite shell attack, and make existence in such batteries, if they are at all crowded, once more intolerable. It remains to be seen whether in that case exposure will be accepted, or a new demand made for armour, at least against the magazine gun and the quick-firing gun. If exposure is accepted, it will be on the ground that the number of men at the guns is now very few, that the gun positions are numerous and the fire rapid, and that, if the guns had once more to be fought through ports in armour, the number of gun positions would be reduced, and the fragments of their own walls, when struck by heavy projectiles, would be more damaging than the projectiles of the enemy."

What is here called the fifth phase is the fulfilment in 1888 of this anticipation of 1885. There has been a new demand made for armour against the magazine-gun, the quick-firing gun, and the shells with high explosives, and the French are once more clothing their ships with thin armour.

Having thus rapidly traced the history of the application of armour to ships of war during the last forty years, the Author will now examine the weapons.

There can be no doubt that the immediate cause of the change in French policy is the assumption that shells charged with gun-cotton, melinite, bellite, lyddite, or some other of the numerous high explosives, will be fired from ordinary guns.

Shells with bursting charges of gunpowder are ineffective against thick armour. To perforate such armour, the walls of the shell must be made so strong that the contained gunpowder-charge would fail to burst them.

More than five years ago the Italian Government experimented with gun-cotton as a bursting charge for shell. At about the same date English artillerists were endeavouring to perfect a delayed-action fuze, so as to delay the bursting of the shell containing high explosives until after the armour had been perforated. Since then every Government appears to have had experience, at the proof butts, of the difficulty of making a trustworthy controllable fuze for this purpose. When this fuze has been established, shells charged with high explosives will come under control, because bellite and lyddite appear to be in themselves perfectly manageable. The French authorities have satisfied themselves that they have brought melinite under control. The introduction of 4-inch side-armour over the batteries proves this. The quick-firing gun will not account for it, because 4-inch armour is perforable at 1,000 yards by the 14-pounder quick-firing guns: and here quick-firing guns, 45-pounders, 55-pounders, and 100-pounders are now being prepared. Moreover, this 4-inch armour will make it even easier for common shells of large calibre, with bursting charges of gunpowder, to be exploded among the guns' crews. The fragments of the armoured walls will be in themselves very destructive.

But it has been ascertained that a delayed-action fuze is not at present procurable, and that the shock caused by 4-inch armour will explode shells with high explosives, fired from moderate-sized guns, on striking. This is why 4-inch armour has been adopted.

The effects of a burst between decks of these high explosives is a matter of experience to some. The French have pursued the subject diligently, and they apparently consider it better to have the armoured walls broken into fragments and scattered about the decks than to endure the explosion of melinite between decks, breaking the beams and frames, upsetting the guns, and paralyzing the crews. But if this is so, and there be any likelihood of having to attack ships like the large French battle-ships "Amiral Baudin," "Formidable," "Amiral Duperré," and others, it is of the utmost importance to be prepared to make such an attack.

The Author knows, from an inspection of the drawings of targets which have been experimented upon with a single charge of guncotton, that a number of heavy 16-inch deck-beams, covering a length of deck of 12 feet, have been broken completely across and lifted 12 feet above the original level. They were broken across immediately over the charge, and from 10 to 14 feet away from this point (at the knees) they were broken again, so that the deck and beams were piled up in a huge wreck at least 12 feet high.

When the large undefended structures in the French ships are considered, the seriousness of this attack becomes evident. And it is the artillerist who must be first impressed. It is of more consequence to be able to inflict damage in war than to be able to resist it. The best defence is to be found in a vigorous attack.

It must be understood that the powerful ships in modern navies are not protected, so far as their batteries are concerned, by the armour which the French think necessary. They are unarmoured from their lower decks upwards.

And now to examine the question as to what is likely to be the outcome of this reintroduction of side armour. Is there any chance that there will be an approximation to finality in the use of such armour?

Look first at the quick-firing gun and see what it will be capable of doing against 4-inch armour. Prior to the introduction of the machine-gun and the quick-firing gun, the most rapid fire of guns, capable of perforating an unarmoured side, did not reach two rounds per minute. The introduction of the Nordenfelt 1 inch machine-gun, with four barrels, raised the rapidity of aimed fire with steel bullets to 120 rounds per minute. These bullets perforate a plate ¾ inch thick at 200 yards. The single-barrelled quick-firing gun of 1·85 inch calibre, firing 3-lb. shot or shell, can get off fifteen aimed rounds per minute. The shot from this gun perforates a steel plate 1·8 inch thick at 1,000 yards. The 2·2 inches single-barrelled quick-firing gun throws 6-lb. steel shells at the rate of fifteen aimed rounds per minute, perforating more than 2½ inches of steel at 1,000 yards, and 4 inches at close range. Armour-piercing projectiles from quick-firing guns will soon follow. The 6-inch 100-pounder is capable of perforating nearly 10½ inches of iron armour at 1,000 yards range, and with steel shell can just get through 9 inches of compound armour at 200 yards. From five to six aimed rounds can be got off from this gun per minute. A further development of the quick-firing system is the automatic gun.

The 3-pounder, 6-pounder, and 50-pounder automatic guns can be fired, with rough aiming at short ranges, at the rate of fifty, thirty-six, and fifteen rounds per minute. With deliberate aim they can be fired with nearly half that rapidity.

It is certain that, apart altogether from these quick-firing guns, it will only be necessary to put up targets of this thin armour, and expose them to the fire of heavy projectiles (shot and shell) in order to show the frightful wreck, behind the target, which occurred years ago, and which led to thicker, and ever thicker armour. But there will be this difference in favour of the gun, that the projectiles are heavier and stronger, the velocities are higher, and the explosives are more powerful.

Experiments have hitherto indicated the certainty that armour will be blown in by charges exploded against it, and that bursting charges with high explosives will be carried through armour probably 12 or 14 inches thick. Now come the questions for the Naval Administration.

1. Is full advantage to be taken of these high explosives in any war which may break out within the next two or three years? To this question the Author can give no answer.

2. How is the new attack to be met in ships? The answer of the French has been seen. They would, if they could, cover their batteries with 4-inch armour.

Another defence is to take care to have a superiority of fire. Any armour carried by an adversary reduces the number of effective shots which can be delivered, because heavier guns must be employed, and the fire must be slower. But 4-inch armour is so penetrable that there will be no difficulty in delivering effective blows. Moreover, the fact that the enemy has armour reduces his armament very seriously. If he should have to fire the guns through port-holes cut in the armour, he will hardly be able to secure his battery from the intrusion of the projectiles against which he has armoured himself. In the French ship "Dupuy de Lôme," no guns are fired through ports. The guns are mounted on an unprotected upper deck. The armour protects them only by keeping out the high explosive shell which might burst under them.

A third way of meeting this new attack is to multiply the ships, with the same expenditure of capital, and thus to limit the loss of capital in a disaster arising from the use of these powerful agents of destruction. If this third way is admissible, it is most clearly to the advantage of England to pursue it. This country, above all nations, needs numbers of ships.

To other powers the significance of individual ships is of most concern. To the English it is important, above all things, to be present in many places with ships capable of attacking any enemy. For every ship of war having 14 knots speed now in the British Navy there are one hundred and thirty-three ships to protect (Table II.).

If the British Government determines to spend money upon invulnerable ships, the difficulty in increasing our relative numbers will be perpetually growing. There is no difficulty, except in finding the money, in making an invulnerable ship. Ships can be built and navigated which no torpedo, nor ram, nor gun which can be worked from any ship now in existence, can fatally wound. In such a ship every man may be absolutely protected, high explosives notwithstanding. But there will be so few of them that commerce and the colonies may be lost for want of ships, and there will only be the satisfaction that the sailors have been protected in such ships as exist.

TABLE II.

——	England.	France.	Italy.	Russia.	Germany.	United States.
Ships of war capable of steaming upwards of 14 knots an hour	92	68	43	22	34	12
Number of merchant ships of 100 tons and upwards to each of above vessels	133	22	40	56	61	303
Merchant steamers of 14 knots speed and upwards, and of 1,500 (gross) tons measurement, and upwards . . .	87	22	4	..	12	..

In order to put forward in a concrete form the Author's view as to the type of fighting ship most suitable for the present needs of the British Navy, he has brought forward a design. It is for a ship of 3,200 tons displacement, costing one-fourth of the so-called first-class battle-ship of to-day. A sufficient number of ships of this type could probably be built and armed in two years, the guns being included in the contract. It may be said that nothing can be done upon such dimensions, and at such cost, which can entitle the ship to be called a battle-ship. It may be well to remember that the seventy-four gun line-of-battle ship of fifty years ago had a total displacement of only 3,000 tons; and that the eighty-gun ship of the same period had only 3,500 tons. This design comes between the two, and will cost as much as three seventy-four gun ships, although, as has been already said, it will only cost one-fourth of the modern first-class battle-ship.

It is difficult to get the sailor to appreciate a money basis. He has to fight in the ships. He sees that his personal chances of life in the smaller ship are less than they would be in the ship costing four times the money, and he naturally values his life and his chances of personal victory more than he does gold. He cannot be expected to see that if four British ships, costing for the four a million of money, destroy or capture one ship of the enemy costing the same amount, at the sacrifice by foundering of the ship which he might command, that that would be an altogether good result.

It is necessary to bring well to the front the enormous increase in the value of the material of war which is entrusted to each captain and to each man in a modern ship. In the line-of-battle ship of fifty years ago, the value of the material for a single command would have been about £100,000, and the value per man in the crews of such ships not more than £150. In the ironclad of 12,000 tons of to-day, the value of ten of the former line-of-battle ships is entrusted to each captain, and not less than £2,000 to each man in the crew. In the ship of 3,200 tons, which is furnished in illustration of the principle of giving preference to numbers of ships rather than to individual costliness, each captain would still control an expenditure twice that required for the line-of-battle ship of fifty years ago, and each man in the crew would represent from £1,000 to £1,500.

The description of the ship may be very brief.

The speed suggested is 17 knots an hour on the measured mile as a minimum. This is 2 knots higher than the speed of the largest armoured ships of France.

There is an under-water deck. It is kept wholly under water, and may be, upon the dimensions shown (but with some corresponding variations in displacement), of thicknesses of from 1 inch to 3 inches.

This deck is covered from end to end by a solid raft of packing material, manufactured by the Woodite Company, which rises above water several feet at the sides, and 6 inches in the middle. This packing-material is practically non-absorbent of water. It will exclude, for twenty-four hours, 96 per cent. of the water which would enter an empty compartment. It requires an appropriation of weight of from 4 to 5 per cent. of the displacement. By this means the floating power of the ship is preserved against sudden destruction under artillery fire. The raft-body can only be slowly destroyed.

For the defence of the fighting position, steel-faced armour 9 inches thick is employed. Within this there is further armour protection, 6 inches thick, over the directing station for the officers.

The order in which protection is given is as follows:—

1. Propelling and steering machinery and magazines.
2. Floating power.
3. Officers at their fighting station.
4. Guns and gunners.

In close action the whole crew may be under armoured cover. The armament is central, with an unrestricted all-round fire from every gun. The guns may either be a pair of 22-ton armour-piercing guns as shown, or a greater number of lighter guns for firing high explosive shells. In either case the mounting is revolved, and the guns are trained and fired by the officers in the central position. The gunners have only to load the gun in their own separate compartment of the revolving mounting, and to connect the firing wires.

The design and the estimated cost of the ship have been prepared by the Naval Construction and Armaments Company, assisted by Sir Joseph Whitworth and Company.

What the Author desires to say is that such a ship may attack fortresses with as good a chance of immunity from destruction from torpedoes and rams as the ship of 12,000 tons; and for the same money there will be four ships to one. The same is true of the defence of ports. As to fighting at sea with other ships, each of these four ships will find perforable to its guns 99 per cent. of the area of the sides of those foreign armoured ships which have side-armour. The ships of 12,000 tons, armed with 67- and 69-ton guns, will find only ½ per cent. more perforable to their guns. There are four batteries, and eight heavy armour-piercing guns in the four ships, and only two batteries, and four heavy armour-piercing guns in the 12,000-ton ship which has cost as much. There are four captains for independent, as well as for united action; four securities against breakdown, or damage by the enemy; and the power of occupying four positions on the field against one in the 12,000-ton ship. The principle holds for ships of larger size, say, of one-third, or of one-half the cost of the largest ship of the enemy.

But the peculiar feature in this design, that is, a single central battery, becomes less advantageous as the ship is increased in size. It is, perhaps, only applicable with undoubted advantage, where at least three ships and three batteries can be brought against the very large ship of the enemy, who may have as many as three armoured positions in one ship.

If it should be said that this dispersion of force entails a risk of destruction in detail, by encounters with units of greater force in the hands of an enemy, that argument simply goes to show that organizing skill will be required to ensure the presence of the united forces where they are needed.

The position is, that to satisfy the demand for superiority in individual ships, an expenditure of one million of money has been reached for a single armed ship.

On examining the ship, as the French ships have been examined, it will be discovered that they are most seriously exposed to the attack of the powerful weapons which are now in rapid course of development. The Naval authorities have to decide for themselves whether they will concur in still further enlargement in individual ships, or will endeavour rather to meet them by combining the forces of smaller ships. It appears to the Author that there is no difficulty in taking this latter course, and that it has many advantages.

The principle of subdivision is consistent with perfect sea-worthiness, with speed as high as that of the largest ships, with the control of weapons which can be used with fatal effect upon the most powerful ships of the enemy; and with such powers of endurance as will enable the smaller vessels to receive injuries from the largest ships without necessarily fatal results.

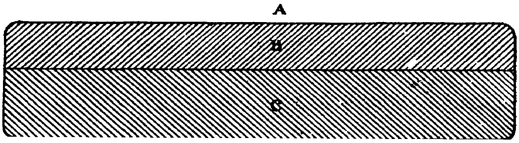
In this exposition of the uses of armour, it has become apparent that fighting ships must continue to use it. When armour is employed in the form of comparatively thin horizontal plating, experiment seems to have shown that steel, low in carbon, is the best material. When it is employed in the form of a wall, either upright or inclined, and comparatively thick, the value of a hard face becomes very marked.

There are three distinct modes of manufacturing thick armour. They are described by Mr. Alexander Wilson, the original inventor of compound armour, and the Chairman of the firm of Charles Cammell and Co., as follows:—

A large wrought-iron plate C (Fig. 2), built up of many thicknesses, is passed through the rolls, and is then, whilst red-hot, pushed horizontally into a huge iron casting-mould A, revolving on trunnions. When the plate is securely fixed, the mould containing it is turned up into a vertical position, and liquid steel, B, is poured from a ladle into a trough, which distributes it in small streams into the cavity between one side of the wrought-iron plate and the side of the mould, precautions being taken to prevent it from flowing elsewhere. When the steel has become solid, the whole mass of iron and steel, which is fused together, is taken out of the mould, and, after re-heating, again passed through the rolls until it is reduced to the thickness required. It is subsequently bent at the hydraulic press to the curvature of the ship, and is then placed on the planing or slotting-machines to be cut to the finished sizes, the drilling of the bolt-holes being the final operation. This is the plan pursued by Messrs. Charles Cammell and Co.

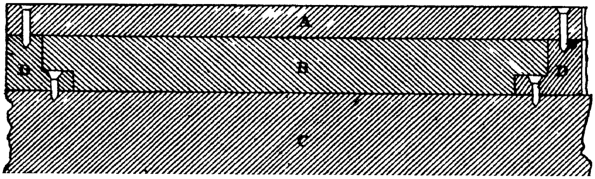
The method adopted by Sir J. Brown and Co. is somewhat different. It consists in taking a wrought-iron plate C, after allowing it to cool, and placing a thin steel plate A a few inches from its face by means of wedge-plates D round the three sides, small steel studs being placed at several points to prevent the two plates from coming too close to each other in the furnace. The whole mass is then heated, taken out of the furnace, and lifted by a crane vertically into the pit, where the molten steel is poured between the two plates from a ladle and trough. The plate is afterwards rolled or otherwise compressed, bent, and machined.

FIG 2.



The Author was greatly struck by the improvement effected by the use of the hydraulic press by Sir John Brown and Co.

Figs. 4 show how much more work can be put into the steel when the press is used as an intermediate process before rolling. Here (*a*) shows how the softer metal, the iron, squeezes out under the rolls and interferes with the proper compression of the steel. (*b*) shows how the steel may be pressed out by local and repeated squeezes of the press, only a very small surface being acted on at each stroke of the press. (*c*) shows, by contrast with (*a*), how the final result is affected. The reduction due to this press, in the internal strains remaining in the steel after forging, must be very important in a thick plate.

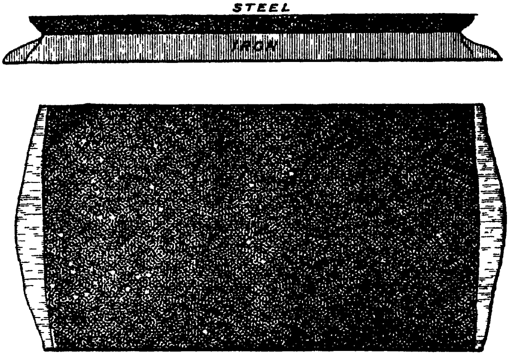


Mr. Wilson describes the successive phases of the manufacture of the forged steel plates at the Creusot works as follows:—

1. The running off, by means of the Siemens furnace, of an ingot proportionate to the weight required for the plate when

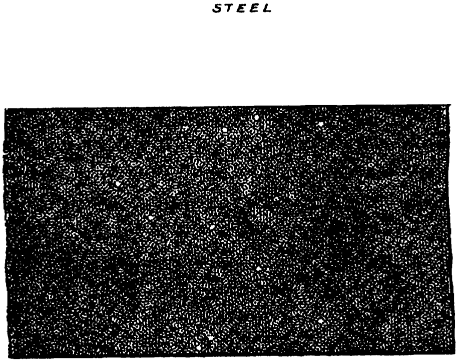
Figs. 4.

a



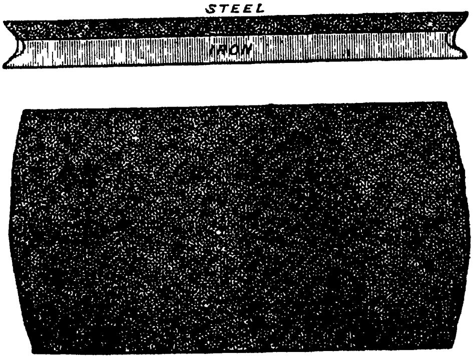
Rolled and not Pressed.

b



Pressed only before Rolling.

c



Pressed and Rolled.

finished; the latter representing only about 55 to 60 per cent. of the steel cast.

2. The heating of the mass in gas-furnaces, and the forging of the plate under the 80-ton hammer.

3. The shaping, either by hammering or with the hydraulic press, followed by annealing in a coal-furnace.

4. The trimming, either with a planer or a saw, when the metal is cold.

5. A first vertical oil-tempering at a high temperature, followed by another tempering at a lower temperature, and often by annealing.

6. The finishing of the plate by the planing off of the ends.

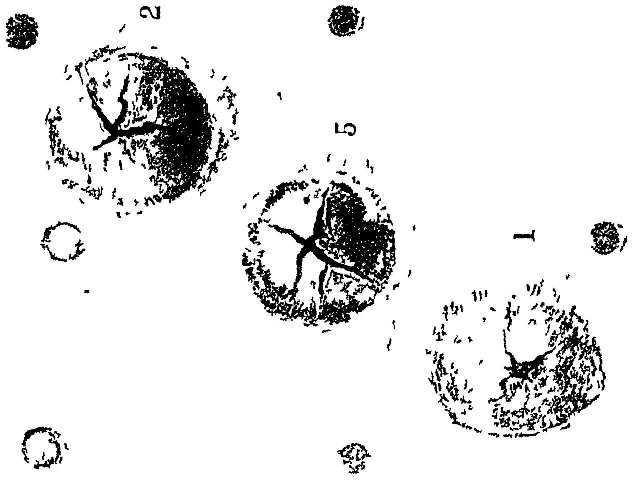
The most successful plate ever fired at in England or elsewhere, so far as the Author can learn, is shown in Figs. 5 and 6; it was tested at Portsmouth on the 24th of March, 1888.

It is a steel-faced plate 10½ inches thick, manufactured, according to their process, by Charles Cammell and Co., and attacked by 6-inch forged steel shot of 100 lbs. weight, and having a muzzle velocity of 1,976 feet per second, and a striking energy of 2,723 foot-tons.

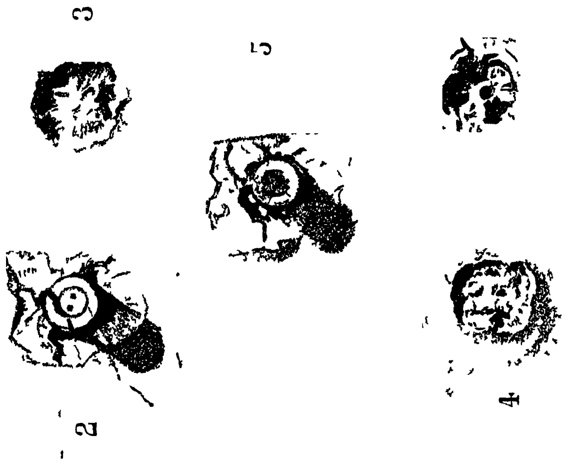
The same firm manufactured, at the same time, a steel plate, Figs. 7 and 8. Mr. Wilson says it is "the first steel plate which has ever withstood such a severe test without breaking up," and that certainly it has proved much superior to any plate manufactured at Creusot which has been subjected to artillery fire. It was tested, under similar conditions to the preceding one, at Portsmouth on the 19th of May, 1888.

In Figs. 5 to 8, the shots numbered 1, 2 and 5 were Holtzer forged steel shell, of 100 lbs. weight, 17⅝ inches long; those numbered 3 and 4 were Palliser chilled cast-iron, of 98 lbs. weight.

The Schneider plates have, he says, invariably cracked through at the second shot, and in the generality of cases at the first, and this with chilled cast-iron projectiles; but the plate under notice, which was subjected to the same attack as the compound plate, not only withstood the two Palliser chilled-iron shells, simply pulverizing them in fact, but also stopped and kept out the three Holtzer forged steel projectiles, and this without showing a single crack. The plate is the first on record which has succeeded in stopping these forged steel shells; and it was sufficiently tough to do this without being itself fractured. Still, when the results are compared with those obtained against the compound plate tested on the 24th of March, 1888, it will be seen how the hard face of the

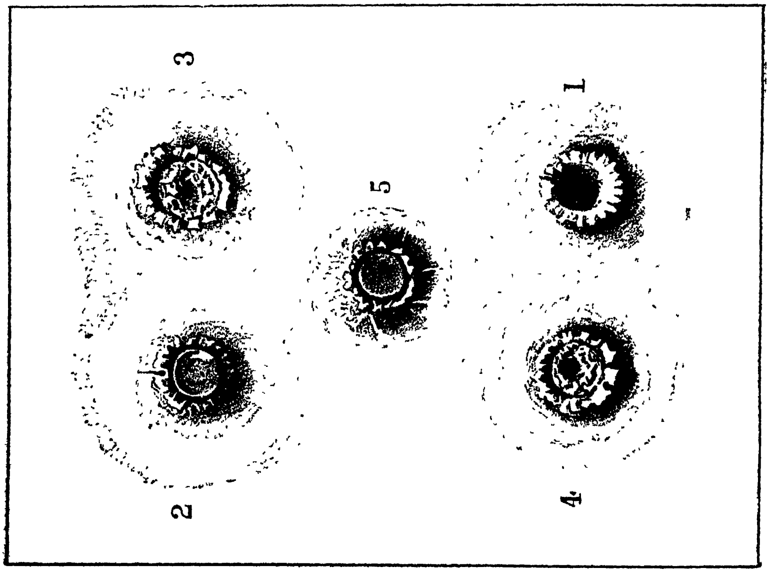


Compound Plate.—Back view.



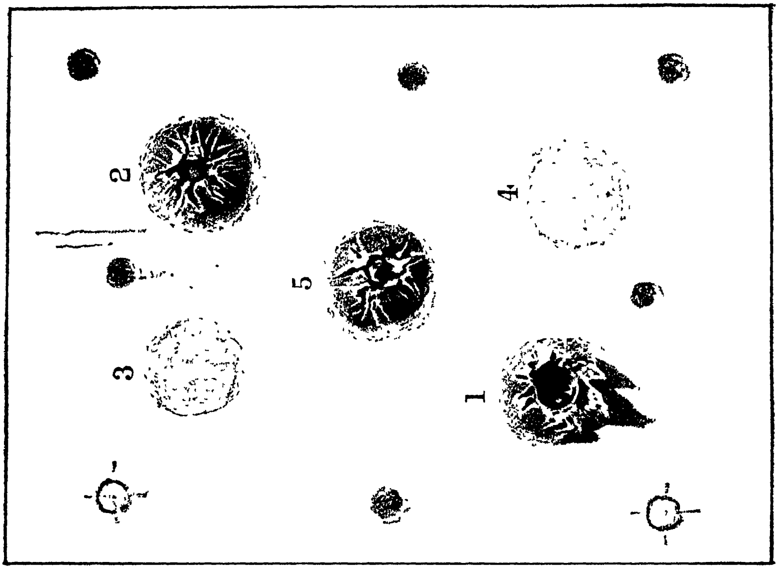
Compound Plate.—Front view.

Fig. 7.



Steel Plate,—Front view.

Fig. 8.



Steel Plate,—Back view.

latter gives it a marked advantage in resisting the perforation of projectiles.

These results are against direct firing; but against oblique firing the advantages of the compound steel-faced system are far more prominently demonstrated.

The Author has treated the subject broadly, and, with the kind assistance of the armour-plate makers, has enunciated the whole aspect of the armour question. He has considered not only what armour is, but how it is employed. It is not a naval question, in the first place; it is one of engineering science. It must be remembered that civil and mechanical engineers have originated all improvements in the types of ships, including the introduction of steam; of the screw; of iron and steel in their construction; and of the use of armour. The great improvements in ordnance and torpedo attack are also due to them. The attitude of the engineer towards questions of war-material differs from that of a member of a political administration, and from that of naval and military officers. The engineer is mainly interested in the question of the development of the powers of the weapons of war, and he is constantly thinking how they may be extended, and how the maximum of power may be got out of a given expenditure. The tendency with the administration is to estimate the comparative value of available resources of rival governments, and not to look beyond the immediate future. It may be seen from the speech of Sir John Pakington, when introducing Navy Estimates, on the 25th of February, 1859, and when the French ironclad sea-going ships were being built, how easy it is to undervalue new forces. This administration undertook the building and conversion at that time of sixty-seven wooden line-of-battle ships and frigates; and they were all in the hands of the dockyard authorities, in various stages of production, a few months afterwards. But not one of them was suitable for the circumstances of the time. Many of them were never finished.

The Author would agree cheerfully to any proposals by the Government, as to the size of the ships, and as to the use of armour for them, if they were laid for approval before some competent technical committee, for a month.

The times are critical, and, if the Author were responsible for the steps which must be taken by the administration, he would insist upon having the soundest independent judgment which could be obtained.

The Author's successor at the Admiralty pleaded for enquiry into the subject in "The Times" newspaper in 1884 and 1885.

He has himself pleaded privately, but through the proper channels, with each administration in turn from that time to this. The difficulties surrounding the question are not lessening; they are sensibly growing.

The Author feels satisfied that if such a body as the Council of this Institution had been consulted in 1868, 1871, and 1875, dates when naval ordnance was in a crisis, and under serious debate, it would not have happened that the question of breech-loading would have been kept closed from 1866 until 1879. He believes that, if such a body had been consulted in 1859, it would have appreciated better the significance of the four ironclad ships then building in France, and the Government proposals would have been wisely modified.

So far as the Author knows, the proposals of the Admiralty (which he has not seen) as to large ships, and the armour for them, may be sound and wise. If they are, it would be very unlikely that such a reference as has been suggested could cause inconvenience or delay.

The Author is not of those who consider it possible to protect sailing ships, and slow steam ships, by means of cruisers in a severe war. Indeed, nothing has been said in this Paper about regular fast war-cruisers. Long before he left the Admiralty, and before the design of Sir William Pearce for a fast cruiser was sent in, a cruiser of 22 knots speed, and to hold 2,000 tons of fuel, had been designed at the Admiralty; but it was decided not to build it. The views which prevailed were very well stated publicly by Mr. George Rendel, who was then, happily, a member of the Board of Admiralty. He said:

> "As far as I understand the question, an alternative is to add to the Navy a number of very swift partially armoured vessels of war specially built to act as the guardians of our commercial ships. Now, there are one or two considerations which seem to make that course a very difficult one. In the first place the number of vessels required would be something enormous. If we make the supreme effort required to provide them, we have to remember that not only would their maintenance be extremely costly, but they would rapidly depreciate in value from the progress in science. As an example, if we assume that that course had been followed some fifteen years ago, we should certainly have had vessels engined in a manner which would have rendered necessary a complete refitting of engines and boilers a few years later, because it would be absolutely essential to maintain such vessels at the maximum point of efficiency, and for this purpose compound engines must have been substituted for the engines previously used. Again, another period of a few years, and we should have found ourselves in the presence of the fact that such vessels must be of steel to cope with their rivals of the day. Again a reconstruction of the fleet. On the other hand, if it were possible to make the Commercial Navy self-protecting, or

to a large extent self-protecting, we should be sure always to have in vessels selected for that purpose the latest improvements, and to have them at a very trifling cost, because, naturally, ships would drop out of the list as others of greater power came in. Then, instead of viewing with as much alarm as pride the growth of our great mercantile marine, we should view it with unmixed satisfaction. We should remove the perhaps greatest preoccupation of those who have to direct our naval policy and naval construction; in short, the object to be obtained is so important that we cannot but think that a very careful examination of the question ought to be made."

But this view does not prevail now. Cruisers of 9,000 tons are being built of the same type as the French "Tage." And yet those who look ahead can see at least two most important elements of change coming into view.

Look, moreover, at the composition of the squadrons in the naval manœuvres in 1888. While England had nearly as many 14-knot ships in her mercantile marine as in the Royal Navy, and almost all of them on the Admiralty List as auxiliaries, yet not one of them was engaged.

The Admirals reporting on the operations draw attention to the proved necessity of having an ample supply of swift cruisers attached to a fleet to keep touch with the enemy, and, as this had been abundantly proved in 1885, it is difficult to understand why no use was made of them.

The Author feels that the difficulty in providing a suitable armament for ships will, for a good many years to come, be even greater than that of procuring ships, and that the merchant auxiliaries will be the last for which provision will be made.

To many minds it seems that the hope of the future, for peaceful sea-traders, lies rather in lessening than in increasing the individual superiority of the special ship of war. They would spare no efforts to raise the character and strength of the fast mercantile ships. But it must be admitted that there is no prospect of a diminution in the use of armour in regular fighting ships. The evident tendency is towards its introduction into every fighting ship.

Recognizing the soundness of judgment of both parties—of those who would improve the regular ship of war, and of those who would develop the latent powers of the auxiliary naval forces—there is another question, and to this the Author has endeavoured chiefly to confine himself.

That question is, Ought England at the present moment to move still farther onward in increasing the size and cost of heavily-armoured ships requiring four or five years to complete, or ought this country rather to endeavour to increase rapidly the number of protected ships, capable by reason of their speed and armament of taking part in any engagement with an enemy, however powerful? And then there is the further question, Is advantage taken of all the national resources in the manufacture of guns, and modern projectiles, and explosives; which will certainly be needed much more than ships are needed?

The Paper is illustrated by several photographs and diagrams, from which the Figs. in the text have been engraved.

Discussion.

Sir George Bruce.

Sir George B. Bruce, President, said he had much pleasure in moving a vote of thanks to Sir Nathaniel Barnaby for his Paper on a question so full of interest and importance to the country. However great might be the divergencies of opinion upon the question, there could be no difference of opinion as to Sir Nathaniel Barnaby's right to speak on the matter, and there could be no doubt that everything he said was worthy of the most careful and attentive consideration, not only in the Institution, but throughout the country.

Sir Edward Reed.

Sir Edward James Reed hoped the Institution would not think him obtrusive, as a Member of the Council, in taking an early part in what must, he imagined, prove a very elaborate and interesting discussion. He was specially charged to discuss another Paper on the following day, and the day after Sir Nathaniel Barnaby would read a very interesting and important Paper at another Institution. He was afraid, therefore, that if he did not avail himself of the present opportunity, he might not be able to speak to the Institution on the subject. The President had used words with reference to the Paper which had been upon his own tongue, namely, that it was a Paper of the greatest interest and importance, and, as he had already intimated, he thought it would furnish abundant material for debate, for it not only dealt with the main question in a very broad manner, but with a number of minor questions, which were sure to excite great interest. He thought it was due to the Author, and to the Institution, to discuss a question like that with perfect frankness and dispassionateness. He therefore hoped that what he said would be carefully watched, for the purpose of ascertaining if he in any way passed beyond fair, legitimate, and real criticism of disputed matter. He wished to guard himself on that point, because he came from another place in which a good deal of heat was generated in connection with the subject. The Author had given a series of what were described as "phases" of armour. They consisted of five circles, the first and last wholly shaded. If it were not out of order, he should like to ask the Author if he would be kind enough to explain what it was that regulated the proportion of shaded to unshaded area in those circles. He had studied them as well as he could, but he had not been able to see on what principle these diagrams were constructed. They were shaded and partially shaded circles, for the

ir Edward
eed.

purpose, he supposed, of indicating to the eye in a simple manner the relation between the armoured and the unarmoured portions of a ship. He supposed, therefore, that the shaded part always represented armour, and he might be right in assuming that it represented armour above water; if so, his difficulty was to ascertain what the unshaded portions represented. Were they the areas of the unarmoured sides of the ship?

Nathaniel
rnaby.

Sir NATHANIEL BARNABY explained that his intention was to show the portion of the ship above water, which in the commencement was completely clothed with armour as represented by the shaded circle. In the second phase, some of the armour came off, a part of the fighting batteries of the ship being left uncovered. In the third phase, there was still more uncovered; in the fourth phase still more, and then the cycle of changes was suddenly ended by a complete covering again of the side with armour. He thought he had made that point clear.

Sir Edward
Reed.

Sir EDWARD REED said that his difficulty was with the diagram of the ship. The area of the unarmoured visible sides seemed much larger in proportion to the armoured than the unshaded part of the circle indicated. However, the Author's explanation would serve all the purposes he had in view. He desired to make a remark about that method of illustrating the state of the armour question. Although he had not the smallest doubt that the Author, in compiling the Paper, had travelled along some clear line of thought, he was entirely at a loss to understand the grouping of the vessels. The circular disks were given to illustrate what might be called the rise and fall and re-rise of the armour. But then this extraordinary thing happened. The Author had introduced into the line of progress a couple of cruisers, and they followed apparently in the line with the line-of-battle ships that had gone before them. The Author, from considerations which would be present to most minds, and no doubt from a desire to avoid as much as possible controversial points, had selected his illustrations from the French Navy, and that had resulted in his introducing into the series of vessels the "Dupuy de Lôme." On the previous evening, in the House of Commons, Sir Edward Reed had mentioned that ship; thereupon the First Lord of the Admiralty sprang up and said that, if the "Dupuy de Lôme" system was considered to be of any importance, he was prepared to combat that idea. The vessel, therefore, was knocked out of his mind on that occasion by a very high authority on those subjects; yet he found it in the Paper occupying a position illustrative of the progress of the armour question. But if the Author had taken illustrations from the British Navy, instead of from the French, it would have been impossible for him to have taken the series of vessels he had chosen, or anything like them, because, while it was true that the English were building huge vessels of 9,000 tons, resembling the "Tage" more than any others adduced, it was impossible to put them into one series of ships illustrating the growth or otherwise of armour, because, simultaneously with the building of those unarmoured ships, the Admiralty was about to build eight ships of 15,000 tons, and two others of very considerable size, for which was claimed more perfect protection by armour than had ever before existed. So that, if that series had been taken from the British Navy and from the succession of battle-ships as illustrating the progress of the armour question, there would have been, instead of the "Tage" and the "Dupuy de Lôme" (vessels covered with 4-inch armour only), the first-class battle-ships now proposed to be built by the Government, and occupying a position of an entirely different character from that which the other vessels could claim. He consequently feared that the outside world (which was a pretty good-sized section) might be seriously misled by the course which the Author had taken. He should have expected to find not a mere solitary cruiser of the French Navy—and a cruiser so bad that the First Lord of the British Admiralty did not hesitate to denounce it the moment it was mentioned in Parliament—but such first-class battle-ships as were now proposed. In that case the meeting would have been led from the "Warrior" down to the first-class line-of-battle ships about to be constructed, instead of from the "Gloire" to the "Tage" and the "Dupuy de Lôme." Sir Edward Reed.

Sir NATHANIEL BARNABY said that he had explained that, when he wrote the Paper, he did not know what the Admiralty's propositions were. He knew nothing of the ships in question. Sir Nathaniel Barnaby.

Sir EDWARD REED did not think that affected his position, because, when the Paper was presented, the Author must have known that the Admiralty intended to continue building armoured ships, and ships of a large class. All that he wished to guard against was the supposition that the course of the armour-plate question in this country was in any way represented by the series given in the Paper. It was nothing of the kind. If, instead of the 4-inch armour-plate vessels, the ships about to be constructed with very thick armour were taken, the cruisers would be relegated to a very different category, and fall under a very different line of thought and discussion. There was nothing in the Paper to show that the Sir Edward Reed.

ir Edward Reed. "Tage" only came into the series as a cruiser, and that the "Dupuy de Lôme" followed in that capacity, and that these vessels did not in any way represent the progress and growth of the armour question, as far as he knew, in France, and most assuredly not in England. The Paper cleared up what had been mysterious to him for a long time, and it raised a question of the most serious and vital character touching the Navy. He had never been able to understand how it was that men of the highest skill and competence in their profession should have produced ships with the extremely limited amount of armour which characterised a great many vessels in the Navy. But the explanation was furnished by the Author, who stated that, in his judgment, it was of more consequence to be able to inflict damage in war than to be able to resist it. He could quite understand that any one with that idea dominant would indeed sacrifice the material which would permit of resistance, and would devote himself to the development of the attacking force of the ship, which was the chief characteristic of many modern vessels. That was a principle right enough, he admitted, if a man were fighting a man, or even an army fighting an army; although even then he thought it would be rather bad strategy never to be seeking to use defensive means that were offered, and always trusting to a superior attack. But in the case of a ship of war the principle seemed to him to be as false as anything could possibly be, and for this reason, that in approaching an enemy on the sea the latter had with him an ally of the most persistent, ever present, determined character that could possibly be manifested, namely, the sea. If the defence were slighted and the enemy allowed to perforate the ship in such a manner that the sea could enter and dispose of it, the enemy would have the advantage not only of a powerful, but of an omnipotent and overmastering ally, who scoffed at all superiority of attack, giving no recognition to the detailed advantages possessed by a ship, but sending everything belonging to it to the bottom of the sea. That in his judgment was the natural consequence of the theory propounded. The Paper, as it appeared to him, denied to the country what it had a right to demand. The Author had very properly said that the question was no other than an engineering one. He had reproached the sailors with having too little regard for money and consideration of cost. Sir Edward Reed reproached the Author with having had a great deal too much consideration for the cost. He thought the country had a right to ask its engineers in designing a battle-ship for the defence of this island (which was in itself little more than a big ship, Sir Edward Reed.

although happily not so sinkable as some ships had been made), "Will you send its protectors out into the Channel on a platform which the enemy shall not be able to send to the bottom readily, which he shall not be able to send to the bottom at all by the attack of light and inexpensive guns, and which, when the worst comes to the worst, he shall only be able to send to the bottom by bringing out enormous and costly guns which shall tax his skill and strength to produce?" There was a striking acknowledgment in the Paper, that in saying that he was not asking the engineer anything that he could not do, because the Author not only laid it down that men could be sent into the Channel upon an invulnerable platform, but asserted that everything could be made invulnerable. "There is no difficulty," he said, "except in finding the money, in making an invulnerable ship. Ships can be built and navigated which no torpedo, nor ram, nor gun which can be worked from any ship now in existence, can fatally wound." (He should like to go a little further and say, which no number of torpedoes, or rams, or guns can fatally wound.) "In such a ship every man may be absolutely protected, high explosives notwithstanding." When a railway engineer was asked to build a bridge across a river, he said to his company: "If you want to bridge the river I will make the bridge, and it will cost you so much;" in like manner why should not the naval engineer say: "If you want a safe ship, I can build it, and it will cost you so much." He did not go so far as the above words of the Author, to which he knew he did not commit himself; he did not want so much protection as there described, but he wanted the platform protected; he had invariably demanded it, and if a contrary resolution were proposed in the Institution, and voted for by every man present, he would nevertheless go on demanding first-class line-of-battle ships so protected that the enemy could not send them to the bottom unless he brought out guns which would severely tax his pocket and his strength to produce. He wanted to know what, as a Naval Constructor, he had to do with cost. People seemed to think that there was a body which restrained and limited the expenditure upon the Navy. That was a delusion. On the contrary, there sat within a few yards of the Institution a body which would sanction any expenditure that a Minister could be got to ask for; and if the House of Commons were told that the Government was going to send men and officers out into the Channel for the defence of the country, on invulnerable and unsinkable platforms, there never would be anything more than that which happened now; somebody who thought that the

Sir Edward Reed. country could do better without any ships at all, or at any rate, that it could do with a much fewer number, would make a motion on the subject; but very few indeed would vote for it, and the great majority of the House of Commons—of every House of Commons that he had known, and he had sat in Parliament for fifteen years continuously—would cheerfully grant the money. He saw present a distinguished officer who had been quoted in the Paper, Admiral Sir John Hay, Bart., and one of the finest records of his parliamentary career was his maintenance, from a naval officer's point of view, of the very proposition he was now laying down, that it was not his business to restrain and hamper his profession with questions of money. Nor was it so with the naval architect, and for this good reason, that the thing to be protected, namely, the existence of the independence of the country, was worth protecting at a very considerable cost. Then there was another proposition growing out of that part of the subject, which he hoped the meeting would allow him to state. He must express some surprise at it, because he always felt that, behind any opinion of the Author's, there must lie a strong thought of some kind; but he was at a loss to understand what the Author could have behind his words when he pointed out that it was for other countries, rather than for this, to care about a strong individual ship; that this country had not the same reason for desiring to have strong individual ships as other countries. He differed entirely from that proposition. He did not deny that the other part of the Author's contention was thoroughly sound and good, namely, that plenty of ships were wanted, and that the power of England should be maintained in a great many parts of the globe. That, he admitted, was a necessity, but it was not the first necessity. The first necessity was the inviolability of England's shores. What was the state of the case as between this and other countries? A seaport town or two might be destroyed in Russia, and tribute levied upon them—what did it matter? The effect was hardly felt throughout that empire. Several towns might even be destroyed in France, yet, such was the wealth and recuperative power of that country, that no mortal blow would be inflicted by anything that could be done to its ports. But in this country nearly all the great towns and cities were ports, or nearly ports, and therefore the first essential to its existence, in a maritime war, was to be able to keep the mastery of the Channel by means of ships individually strong, and as compared with other powers, so to say, omnipotent. And simultaneously with that, a multitude of ships should be secured for the multitudinous services which the Navy was called upon to

Sir Edward Reed.

perform all over the kingdom. But, notwithstanding what he had said, he was extremely disposed to go a long way with what seemed to be the main contention of the Author, namely, the multiplication of small ships, individually far from weak, for attack or for defence, and of moderate size and cost. The reason was that he could not get the invulnerable ship built; he could not get the safe platform constructed. It seemed to be the determination of every constructor, who had power and responsibility, to make it his care not to give the ship an invulnerable platform which the enemy could not easily dispose of. At the present moment this country was in the position of being about to vote eight millions of money for eight ships which did not to his satisfaction fulfil that primary condition, but were distinctly made in such a way that they could be destroyed without the attacks of the very powerful guns to which he had alluded. Since, therefore, the proper ships were not to be had; since ships costing a million of money were exposed to going down to the bottom of the sea because they had been denied the necessary armour of defence—the necessary height and depth—he felt persuaded by the Paper into the course of preferring the multiplication of ships of less size and cost, and taking the chance with them. The vessel proposed by the Author was, to his mind, one of an extremely interesting character. Regarding the sea as the enemy's most destructive ally, when once allowed to enter in sufficient quantity, and feeling that the invulnerable platform could not be obtained, the question arose whether, as the ship must be destroyed, it was not better to adopt the Author's design. An idea in a vague way had sometimes passed through his own mind, whether a vessel should not be produced defended in regard to the engines and boilers by an under-water deck, then filling it up from that deck to a substantial height above water, so that the enemy could not sink it by fire, except by the comparatively slow process of blowing out that solid, but light material. It was a conception which seemed to him to be extremely full of interest, and thoroughly worthy of study and consideration. The thing about it which he did not like (it was a mere matter of detail) was that the Author had not in his judgment carried that solid substance up high enough above the loadine. He could not reconcile his mind to vessels which sank when a little water was let into them. He thought they ought at any ate to be able to take some water on board and still keep afloat. f there was only a margin of 6 inches, as allowed in the Paper, or the solid material above the load water-line, he thought that was not sufficient. This was very much the same question as that of the belt. Why he detested the belt for a line-of-battle ship when narrowed down, as it always was, was this: If the belt was 6 or 8 feet high, or even 4 or 5 feet, a certain quantity of sea could be admitted, or an extra quantity of stores taken on board, and still the vessel would remain a safe, satisfactory fighting vessel; but if the belt was designed to be 2 feet 6 inches above water, and if it came out, as it often did, only 1 foot 3 inches above water in the finished work, the margin was gone. A desperate effort was going to be made against that in the new ships. He believed the Board of Admiralty had determined to exercise a little direct control over the designing, and the intelligence and knowledge displayed in Parliament encouraged him to believe that many things would be done if it had full scope. One of the instructions to the Constructor was, "For the future you must allow a margin of displacement," and he believed that 4 per cent. was what had been imposed upon him. That was a very wise thing; but then the Constructor, although he had given 4 per cent. margin of displacement, had provided for a very small coal supply; and before the ship was finished he was told to double it, and, when doubled, the margin was all gone. He had no doubt that that was what had been done, and that was how it happened that a first-class British iron-clad, costing a million of money to defend the interests of the country in the Mediterranean, with 13,000 indicated HP., was to be allowed 900 tons of coal. There was an odd remark in the Paper which he hoped he might be excused for noticing. The Author had quoted from Mr. George Rendel, and he had introduced the quotation by stating that Mr. Rendel was then "happily, a member of the Board of Admiralty," and, as an illustration of the happy effect which he had on the Board, it was stated that when the Author designed a cruiser of 22 knots speed, and to hold 2,000 tons of fuel, it was decided not to build it. He did not wish to say anything reflecting upon Mr. Rendel, but, if his influence on the Board of Admiralty was to prevent fast cruisers from being built for the British Navy, the inference he should draw would be not that it was a happy circumstance that he was on the Board of Admiralty, but that it would have been a much happier one if he had been far away from it. The fact was now acknowledged that the Author had been for several years urging the Admiralty to constitute a body to enquire into that great engineering question upon which millions of money were being lavished from the accidental causes of the moment, and the Author had mentioned what was perfectly true—that Mr. White, his successor, like himself, had advised independent enquiry. What was the result of it? An expenditure was about to be incurred, not quite so much as some people supposed, but of about sixteen millions, upon ships from the design of one gentleman. He was a thoroughly competent man, and he would always bear the warmest possible testimony to the ability of the present Director of Naval Construction. He was no doubt one of the ablest designers; indeed, the only doubt he had about him was whether he was not a great deal too able. He had lived long enough in the world to be more afraid of very clever people than he was of moderately clever ones. But the situation of things at present was that the late chief Constructor of the Navy was inviting enquiry, that Sir Edward Reed, a predecessor of his, was urging enquiry, that the present Director of Naval Construction was urging enquiry—that all enquiry was denied, and that millions were about to be expended upon the designs of a gentleman who was an apprentice when Sir Edward Reed was Chief Constructor, and who, with all his ability, might possibly be very beneficially restrained by the bringing of other minds independently and freely to bear upon the subject. Millions were to be lavished upon these hole-and-corner designs. He joined with the Author most cordially, first, in believing that if the Council of the Institution had been invited to deal with the question from time to time great public evils and public waste would have been averted, and that, if such a body were now called in to advise the Government of the country before launching out into such an immense expenditure on designs which he condemned, and which the late Chief Constructor most delicately, but, nevertheless, most powerfully, called in question, an enquiry might be raised which would save all that expenditure, and which would lead the country, as it ought to be led, by sound, good, broad, professional advice, along that path which ended either in the vindication of its greatness and the preservation of its power, or in overthrow and destruction, under conditions which would terminate its career in an unjustifiable neglect of the known resources of civilization. Sir Edward Reed.

Sir NATHANIEL BARNABY asked permission to make an explanation concerning the material proposed to be employed as solid raft packing for the defence of buoyancy and stability in small fighting ships. Since the Paper had been read, his attention had been called to the fact that specimens of the material had been sent out by the Woodite Company which, in the conditions in which they were sent, were very far from being non-absorbent of water. He ought to have observed that himself, but he had not done so. The material, as he accepted it, was non-absorbent of water, and Sir Nathaniel Barnaby.

Nathaniel rnaby.

he submitted specimens which, without any envelope or external waterproofing, were non-absorbent. In order to reduce the price and the weight of the material, the manufacturers had produced what they thought to be a better result. They produced blocks not weighing more than 16 lbs. per cubic foot, and they subsequently "waterproofed" those blocks, as shown by the specimens. That latter material when waterproofed weighed, as he had said, about 16 lbs. to the cubic foot, and cost £45 per ton. It was impervious to water so long as its jacket remained unbroken. If its jacket was broken the internal packing admitted water. It did not absorb water into its own structure, and it did not appear to suffer disintegration. The material thus presented two aspects. (1) A material impervious to water, and weighing less than he gave as a weight which could be accepted. (2) A material very much lighter when unjacketed, which was pervious to water, but which was intended to be jacketed, and was then watertight.

ice-Admiral Ioward.

Vice-Admiral E. H. Howard said it had been stated by the Author that he could build four of the vessels described in the Paper for one of the monster ironclads designed by the Admiralty, and that he thought was a very important point. Superiority in numbers was a great advantage, giving, as it did, different points of attack. Besides, the four vessels would have four independent heads. The present practice was to make everything dependent on the captain of the ship, and to put everything under his control. The responsibility, therefore, of the captain of one of the large ships would be very great indeed. In the case of the four vessels that responsibility would be divided, and, for his own part, he would much rather have command of the four ships than of the one ship.

Captain Fitz-Gerald.

Captain C. P. Fitz-Gerald, R.N., said he had the misfortune to be opposed to the Author on more than one occasion; but he knew that the Author would be the last man to deprecate fair and honest criticism, and he would be able to reply to any observations that were made. He also had the misfortune to differ from Vice-Admiral Howard, with regard to his statement that four weak ships were better than one good one. How he was to command four ships in action he did not know; any captain would probably find it sufficient to command one. If the four ships could be worked under the direction of one brain, there might be some soundness in such strategy, but he held that to be impossible. Signals in the heat of action would be of very little use. The four ships would be governed by different brains, and it would not be possible to bring them all to bear upon the decisive point at the decisive moment. It had been

Captain Fitz-Gerald.

laid down as one of the first principles of war, either on shore or at sea, that there should be the greatest possible force at a given point at a given time. That principle had been a favourite maxim of Napoleon's, and had been followed by all the great captains of all ages. With the suggested division of the responsibility, in the four ships, he did not see how that happy conclusion could be arrived at. He was a believer in what had been called the moral effect in war. No doubt the words had been much misused; but still the fact that an army or a fleet thought itself superior, either in weapons or in any other way, to the enemy it had to fight, was admitted on all hands to be a very important factor in the case. Whether it was a magazine rifle, or a breech-loader, or a more powerful ship, it gave confidence to the men who were going to fight. He knew that it was the fashion to say that the whole business of naval war was being reduced to a matter of mechanical engineering. He ought to speak with caution on the subject before civil engineers, because naturally their minds would be concentrated upon the question of engineering. Naval battles were, in their view, to be fought by machinery, by the turning of a crank, the pulling of a handle, the discharge of a torpedo, or the firing of a gun. He did not believe in that, and he maintained that the personal element—the fighting men themselves—would enter as largely as ever into the question. To go on any other principle would be making a very great mistake. The effort to put the eggs in different baskets was, he believed, a departure from sound principle. The question had been argued from many points of view, and the Spanish Armada had been cited as an instance. The English were said to have had then a larger number of quick-working small ships than the Spaniards, and could therefore buzz round them and attack them as they liked. Professor Laughton, however, had exploded that theory. In a recent lecture he had shown that not only had the English more guns, but heavier ones, than the Spanish, and that they destroyed the enemy by superior seamanship and superior artillery power, and in other ways into which he need not enter; the English certainly had superior speed and mobility, which was another point of great importance. The Author had put forward a ship of 3,200 tons, going at a speed of 17 knots an hour. Such a ship might possibly attain that speed, but under what circumstances? In dead smooth water. It was well known that a small ship could not keep up its speed like a big ship in rough water. The speed fell off at once, and it was impossible to compare a ship of that kind with one of those magnificent designs of Mr. White's recently brought aptain Fitz-erald.

forward at the Institution of Naval Architects. If a seaman were told that the small ship could keep its speed under the conditions that it was likely to meet with in the ocean, he simply would not believe it. As to the point of tactics, it was all very well to say, "If you bring out your one monster, I will attack you with five ships; I have so many more guns and so many more chances than you." It should be remembered that these five ships would get in each other's way, and would very likely run into each other. Besides, a battle ship did not go out to fight alone; there was usually a fleet, say of half-a-dozen ships, and such a fleet would require thirty small ships to attack it. Those thirty small ships could not all be on the same piece of water at the same time, and could not fulfil the first principle of strategy, that of bringing to bear the greatest force at the decisive moment. The Author had quoted a passage from Admiral Touchard, and had thus given it the imprimatur of his authority, expressing sentiments with which Captain Fitz-Gerald could not agree. He also said, "It is difficult to get the sailor to appreciate a money basis. He has to fight in the ships." No doubt it was difficult, and he hoped it would remain so. Naval men did not care about the money; the tax-payer had to provide that. Sailors wanted the best of everything to do the best work; and he believed that the policy of building cheap ships, knowingly inferior to those of foreign nations, was a totally wrong policy. The Author said: "He sees that his personal chances of life in the smaller ship are less than they would be in a ship costing four times the money, and he naturally values his life and his chances of personal victory more than he does gold." He did not suppose that the sailor would think much about his life, when once he was engaged in fighting, but he did value his chances of victory. It was all very well to put him in an inferior ship, and say, "It is true you will be sunk, but it will not matter, because there are others to take your place." That was a false position to place him in, and it was depriving the service of one of the first principles of warfare, namely, that of giving confidence to the men in the ships in which they fought. To endeavour to impress the men with the money value of the ships was a great mistake. The captain, whether of a torpedo boat, or of a line-of-battle ship, carried into battle with him his life, his honour, the honour of his country, of his flag, and of his profession; and he thought that was quite enough without impressing upon him the fact that his ship cost a million of money. He therefore came to the conclusion that the only policy for England, as a rich nation, was to have the best of everything, and to pay for it. He could quite understand a poor nation building a large number of cheaper ships, and trying to multiply its chances in that way; but England had to protect the commerce of an enormous empire, the richest that the world had ever seen, and the envy of all other countries; and it was absurd for her to haggle over the price of defending it. Whatever might be the cost, it could bear no reasonable proportion to the riches to be defended, and the only possible way of defending them was by absolute supremacy on the sea, both as to number, and as to the individual fighting ships. Captain Fitz-Gerald.

Admiral H. Boys said the Paper began with a matter of almost ancient history which he well recollected. The tenour of the Author's remarks appeared to be that naval officers in those early days, instead of endeavouring to advance the science of ship-building, were rather disposed to check it. It was stated that "the captain of H.M.S. 'Excellent,' reported in 1850, that 'whether iron vessels are of a slight or substantial construction, iron is not a material calculated for ships of war.'" He well recollected those experiments. They were made by firing at one of the first iron-built ships, at a distance of about 400 yards, with 32-pounders. The material of the ship was called iron, but from the fractures and the debris thrown about inside the ship, the results were somewhat similar to breaking a pane of glass with stones. He thought the officers who made the trials were quite right in saying that that was not a material that should be used in the construction of war ships, and in doing their best to prevent its use. With regard to the statement that "seventeen iron ships, which had been in process of construction for fighting purposes, were thereupon condemned as useless for war-service," he could only say that that was the first time he had heard of it. As to the question of vulnerability of the water-line of ships against artillery. When ships were perfectly steady, and in smooth water, perforation under water was almost impracticable, because immediately the shot touched the surface of the water it ricochetted and skimmed above it. In smooth water there was no reason why the water-line should be protected with armour more than any other parts of the ship. With regard to rolling-motion, he believed that the rolling "period" of vessels of that description was about ten or twelve rolls per minute; or say one roll in six seconds. Considering that a ship would roll both ways its dangerous zone would be out of water only half the time, and that would make it three seconds. Then it should be remembered that the attacking ship would be rolling, so that the three Admiral Boys.

miral Boys. seconds would be reduced to one-and-a-half second, which would be all the time that the vulnerable part at the water-line would be exposed to fire. It should also be borne in mind that ships would not be rolling the same way at the same time; if one rolled one way while the other rolled the opposite way, the guns being fixed to the deck could not be pointed to the water-line at all. Then there were two other points to be considered. There was the probability of the swell or wave intervening, as occurred with a ship to which he once happened to belong. A slaver was taken by a ship of which he was gunnery-lieutenant. It had to be destroyed, as it could not be sent to port. It was a nice "innings" for him to have a day's practice to sink the ship. The slaver was anchored 200 yards from the steam-frigate, both ships rolling from 5° to 10°. The vessel was fired at with 68-pounders and 10-inch guns. He anticipated that it would be possible to sink it at once, but the frigate expended the entire allowance of ammunition without sinking it after all; it was not possible to get a shot in between wind and water, and it was found necessary to take gunpowder on board, and blow the vessel's side out. In olden days when ships fought under sail, there was the question of weather-gauge. Ships were then always under pressure of sail, and they heeled over, the lee ship had the weather-bends thoroughly exposed to the fire from to windward of the numerous guns carried by ships of those days. The guns perhaps could not be aimed as accurately as those of the present day; but considering that there might be fifty or sixty guns peppering away at a ship's weather side, the chances were that some of the shots would enter below the water-line, and even then the vessel need not necessarily sink immediately. It seemed to be implied that those on board ship had no means of pumping the water out, or taking steps to keep the ship afloat, supposing she should be dangerously wounded. The other point was the personal error of the firer in taking a snap shot from one rolling ship at another. Altogether, he considered the risk to a ship from the penetration of projectiles at the water-line had been very greatly exaggerated. There was a point referred to at p. 21 of the Paper in which he could not agree with the Author. "It is not a naval question, in the first place; it is one of engineering science. It must be remembered that civil and mechanical engineers have originated all improvements in the types of ships, including the introduction of steam; of the screw; of iron and steel in their construction; and of the use of armour." He would quote only a few lines that appeared a week or two ago in a journal which took another view of the subject. "Science, with her usual pedantic imbecility, has been building ships for some time under the inspiration of algebra, and with an utter disregard for certain simple practical considerations. The sea after all is a very rough road at times, and knocks about whatever goes upon it without mercy." He could not agree that the question was not a naval one. The naval officer was as necessary to the engineer as the engineer was to the naval officer, and the two could not be dissociated. The screw was the invention of a naval officer, Captain Smith; at any rate it was introduced into practical use by him. It was at the suggestion of naval officers that many of the improvements introduced had been made, and he believed it would continue to be so. The Author had stated that he felt satisfied "that if such a body as the Council of this Institution had been consulted in 1868, 1871, and 1875, dates when naval ordnance was in a crisis, and under serious debate, it would not have happened that the question of breech-loading would have been kept closed from 1866 until 1879." He would appeal to any naval officer, if, during that time, the muzzle-loaded rifled guns were not perfectly efficient. The greatest artillerist of the day, who was one of the brightest ornaments of the Institution, and who did more to reform gunnery than any living man, Lord Armstrong, though he had first instituted the breech-loading gun, reverted to the muzzle-loading gun, and made it a serviceable weapon. He did not say that he was at present an advocate for returning to muzzle-loading guns; but at the time he referred to they were certainly the best obtainable, and it was the introduction of slow-burning powder requiring long barrels which could not be loaded inside the ship that had led to the present breech-loading system. The muzzle-loading guns were, on account of strength and simplicity, the most suitable for any naval operation; they were accurate enough, penetrating enough, and were rapid enough in firing, and there was at that time very good reason for adhering to them. He differed from Captain Fitz-Gerald as to the tactics of smaller vessels in competing with large ones. The ram of a vessel of 3,000 tons, going at 8, 10, or 12 knots an hour, was quite sufficient to destroy the biggest ship that was ever contemplated. As to the class of ship proposed by the Author. In action, there must be four or five of those ships to compete with one of the larger new ships. With respect to the ram, one was as good as the other. He would, for the sake of illustration, call the large one "Goliath," while the four smaller ships might be called "Monday," "Tuesday," "Wednesday," "Thursday." By a preconcerted arrangement, and

Admiral Boys.

iral Boys. as a point of honour, it should be agreed between the four ships that on whatever day of the week an action might be brought on, if, for instance, on a Monday, the ship called "Monday" should run any risk in order to hamper the movements of the "Goliath," if necessary to get across her bows to be rammed. He maintained that even a 14,000-ton ship with one of 3,000 tons hanging to her stem must be stopped; then the "Goliath" would be at the mercy of the other vessels "Tuesday," "Wednesday," and "Thursday," to ram her on either side. These were the main arguments in favour of numbers, as proposed by the Author, against size.

White. Mr. W. H. White observed that when Sir Nathaniel Barnaby spoke on such a subject as that under discussion, everything he said must be listened to with respect. When a man had spent forty years of his life almost entirely in endeavouring to strengthen the Navy by the addition of efficient ships, and when he had often to keep his mouth shut when anything but fair attacks had been made upon his professional work, clearly when he came forward in public, and gave his views upon the past, present, and future, all were bound to attend to him. He was the more careful to say that at first, because, nearly all that he was about to say would be in the sense of differing from the Author. When the Author came forward, it was to be assumed that he came for the purpose of provoking discussion, and of getting as far as possible the opposite points of view clearly stated. First he wished to take strong exception to the historical "phases" represented in the diagrams. And he did so for this reason. On reaching the year 1880, there was a change in the type of ship. The "Gloire," to begin with, was distinctly a battle-ship; the "Marengo" in 1869 was still a battle-ship, and so was the "Baudin," in 1880. After that time the battle-ships were conspicuous by their absence, and they began again. It was not in the same sequence at all. The series began with a cruiser, the "Tage," built for a distinctly different service, and the "Tage" developed into the "Dupuy de Lôme," again a cruiser. Of course it might be said that that was merely playing with names, and when ships of 7,000 tons were built, to talk of them as not being battle-ships was incorrect. He did not wish to bandy words about it, but he would put the case as it presented itself to him. There was now building in France a battle-ship, the "Brennus," and if that vessel had taken the place of the "Tage," at the date of 1887–8, there would have been altogether a different condition of things. He of course knew more than he could say about the "Brennus," but taking what had been published about the ship, it had a thick armoured belt and strong-armoured gun stations, and the question of protection of the side above the thick-armoured belt was one which he believed had not yet been definitely decided. That led him to a point which he desired to make most clearly, namely, that in discussing the matter a distinction must be kept between battle-ships and cruisers. He had no doubt that if Captain Fitz-Gerald and other gallant officers found themselves in vessels called cruisers, and came across a vessel called a battle-ship, which, because of size, or some difference of construction, they thought they could safely engage, they would do so. But that was not the point. The point was, that there were afloat in other navies certain great ships possessing features which could only be attained in ships of large size; other nations had been and still were producing battle-ships, and the question was, how could those vessels fairly and with the greatest certainty of success be met on equal terms? He did not say that numbers should not be developed and many cruisers built; but the point he was trying to make was that it was unwise on any mere *a priori* argument, obtained even from the highest source, to be content to rest the defence of all that was most valuable to the empire upon ships which were individually and distinctly inferior to those possessed by other countries. If that principle were admitted as the principle on which the Admiralty policy should proceed, it would be seen that there was room enough in the Navy for battle-ships and cruisers, and he wished to point out that in the Admiralty programme which was now before the country, and which included seventy ships, there were only ten that came into the category of battle-ships, eight of them being very large ships, of which so much had been said, and two vessels of more moderate size. Sixty out of the seventy vessels belonged to the class of cruisers. Nine of them would be large cruisers, and approximately the same size as the "Tage," but swifter, more heavily armed, and better protected. Thirty-three would probably be vessels of about the same displacement as the design exhibited by the Author, and the remainder would consist of smaller swift torpedo gun-boats. In view of the almost absolute want of experience in naval warfare under modern conditions, was it not unreasonable that this country should proceed on any merely doctrinaire course, rather than that in the creation of its new modern fleet it should have all classes of ships represented? He would pass by for the present any consideration as to whether the designs were what they should be—the best that could be produced; on that point he would say a word further on. The question was whether, as a matter of policy, so much being unknown, it was

Mr. White.

White. not the wisest and best thing to provide against all risks. At the risk of repeating what he had recently said, and in order to complete his remarks, he desired to state in the briefest way what were the principal advantages belonging to increase in size. Captain FitzGerald had referred to one, namely, the maintenance of speed, and of that there could be no doubt. Then there was a further and very important thing—steadiness of gun-platform, of which also there could be no doubt. Then there was the enormous increase in the power of concentrated attack which came from having a large armament carried in a single ship under a single direction. Further—and that was the point often overlooked—there was the fact that a large ship was much less likely to be destroyed or put out of action by a single heavy attack, whatever form it might take, than a small ship. It was conceivable that a single heavy shell bursting in the vessel proposed by the Author might make it unworkable. Notwithstanding the packing material and the under-water deck, a single heavy shell exploding therein with such explosives as were now known, might for all fighting purposes destroy the ship, but with a ship that was very much longer and very much larger, and which had its armament very much more widely distributed, clearly the risk of destruction by a single heavy attack was greatly reduced. He believed that in fortification the doctrine that he had tried to illustrate took the form of saying that a large place was a good place to defend. He thought that those points for the large ships were clearly points that could not be ignored. Of course, they must be paid for. Suppose that four or five ships could be built for the cost of one of the big ones: if what he had put forward was correct, it did not matter whether or not four or five could be built for the price of a large one. If the large one was necessary it must be constructed. What he wanted to present to the meeting was the idea that for the English there was no necessary choice between the two alternatives. It was sometimes put to them as if their finances had run so low that they must multiply small ships and could not afford big ones. He did not consider that that was the real condition of things. There was room in the Navy, with its great range of duties, for all classes of ships, and there might even be room for the class suggested by the Author. In criticising the design he was quite sure that the Author would take in good part what he was about to say. To his mind there could be no defence whatever for putting a protective deck in a ship of war wholly under water, because, for all practical purposes, the bringing of the deck above water did

Mr. White. not sensibly increase the risk of its being directly attacked; but if it was put entirely under water, clearly the space contained below the protective deck in no sense assisted the maintenance of buoyancy and stability, when the upper works were damaged in action; the maintenance of these qualities depended chiefly upon wood or woodite packing above the deck. Further, he conceived it to be a doubtful principle, notwithstanding the high authority which recommended it, to put relatively large weights into the form of packing material which added little or nothing to the defence. The woodite, according to the Author, weighed from 4 to 5 per cent. of the displacement; that must mean about 140 or 150 tons weight put into the woodite for the single purpose of protecting the buoyancy and the stability within moderate angles of inclination. Supposing the protective deck to be elevated, as was now almost universally done, so that it came above the water-line, for a considerable portion of the length of the ship the need for the packing material was reduced without prejudice to the maintenance of buoyancy and stability. Supposing further that the same weight which was put in the packing material was put into coal, there was a defence which, as was well known from experiment, was of enormous value against many forms of attack; the coal was a usable material in the ship, and it might happen that the possession of that additional coal in such a ship would mean the fulfilment of a duty that would otherwise be impossible. His opinion, therefore, taken for whatever it might be worth, was entirely adverse to the adoption of a type of ship which depended for flotation upon packing material which was not in a usable form like coal, and which added but little or nothing to the defence. And it was to be noted that in some foreign navies, where the opposite rule had been adopted a few years ago, a change had been made in the later ships in the direction he had indicated. The Author in his Paper had not made any allusion to the Admiralty designs, but of course it was impossible to discuss the question without referring to the designs which were now before the public. Sir Edward Reed, in opening the discussion, distinctly did not avoid reference to those designs, and he therefore hoped that he should be in order in making a few remarks on this subject. The objection made to the designs for the large battle-ships had taken this form, that the ships were too large and too costly, and had too much armour according to the Author's view, and that according to Sir Edward Reed's view they had not armour enough. Might it be permitted to those who had to do with the designing of these battle-ships to hope that between two such authorities they had struck the golden mean.

hite. He spoke simply as representing the Admiralty, which, as was well known, had not proceeded lightly on the course that had been followed. Never in the history of the Navy, as far as he had known it, had there been more careful or even as careful deliberation given to any question. The magnitude of what was contemplated had been fully understood and appreciated, and the country was in the position of knowing what had been done by the papers that had been presented to Parliament. Sir Edward Reed had said, and Mr. White distinctly challenged the assertion—"All inquiry was denied" about the new designs, "and that millions were about to be expended upon the designs of a gentleman who was an apprentice when Sir Edward Reed was Chief Constructor, and who, with all his ability, might possibly be very beneficially restrained by the bringing of other minds independently and freely to bear upon the subject. Millions were to be lavished upon these hole-and-corner designs." "Hole-and-corner designs!" Designs prepared after months of consideration by the Board of Admiralty! Designs which were submitted to and selected by such a mèeting of experienced naval officers as had never been before summoned. Designs which he had recently described in public in the presence of Sir Edward Reed, challenging him to justify any of his criticisms on their character. He would leave it to the Institution to judge if such a description as "hole-and-corner designs" applied to a course of proceeding in which the Admiralty had taken the only means of publicity in its power, and had brought to its assistance the best naval advice it could obtain. Perhaps he might be permitted to add one word on the personal reference without offence. He had always thought that it was the privilege of Members of the Institution among whom he had the honour to number himself, that biographical notices should be reserved till they became obituary. Sir Edward Reed had done him the honour to bring to the notice of the Institution the fact that he was once an apprentice. It was perfectly true, and he was delighted to think that it was true. He thought that all who went in for applied science were the better for knowing the use of tools. But he might also add that he was not so young as he once was, although he should never, during Sir Edward Reed's lifetime, be as old as Sir Edward was. With all his rapidity, he could not overtake the start which Sir Edward Reed had attained by the accident of birth. But for twenty-two years he had been continuously engaged in that not very pleasant occupation, designing and building ships, and he thought he might say without egotism, that he had had special opportunities of acquiring information, and he hoped in the public

Mr. White. interest that he might prove capable of usefully applying information so gained. With that remark, he would pass away from the personal reference, and simply say that, at the Institution of Naval Architects, he had dealt with every point of a technical nature which had been raised by Sir Edward Reed; that he had dealt, he thought, to the satisfaction of the members present, with all those points, not as matters of opinion, but as matters of fact. With reference to what Sir Edward Reed had said in regard to the coal supply, that given to the new designs was determined by the Board of Admiralty, and was in excess of that of nearly all the battle-ships afloat in the English Navy, and greatly in excess of that of nearly all battle-ships of foreign navies. He wished to say one word as to the history of a design in the Admiralty, because he should extremely regret that a matter of public importance should degenerate into anything of a personal nature. The naval members of the Board, having before them existing types of ships, desired to embody in some new ship certain features of armour, armament, speed, protection, and coal supply. Those features having been decided upon, it became his business, as the responsible naval architect of the Admiralty, to embody them as best he could in a ship that should be seaworthy, habitable, and capable of attaining the speed and traversing the distances which the Board of Admiralty decided upon as desirable. To speak, therefore, of millions of money being lavished upon his designs under these circumstances was, he thought, scarcely a complete description of what happened. The designs which had been adopted, it could not be too often repeated, had been most carefully selected by the most experienced officers of the Royal Navy, both at the Admiralty and elsewhere; and, whatever might be their merits or demerits, it was not fair or correct to describe them as emanating from his brain, or to attribute their existence to any initiative of his own. He need say no more about those great ships, except to add that he was certain that even the Author, with his recommendation of smaller ships, less costly, and less armoured, would admit that the addition of those large ships to the Navy must greatly increase its force. With regard to cruisers, he must again differ from the Author with great respect. When he spoke of the defence of the mercantile marine, and appeared to recommend, on the authority of Mr. George Rendel, allowing the mercantile marine to take care of itself, he overlooked the fact, that, in foreign navies, there were great numbers of specially designed men-of-war cruisers which had to be met by something. He agreed with everything the Author had said about the desirability of arming and using

White. the splendid merchant steamers which the country possessed, whenever circumstances of war should arise. It was a perfectly distinct question what these vessels should be used for; how best they could be employed was a matter that would be decided when the time came; but he was convinced that there would be work enough found for the greater number of them without expecting them to take the part of improvised cruisers belonging to the Royal Navy. But if they should be so employed, the question to be asked was, were these vessels expected to meet the men-of-war cruisers of foreign navies? Was it to be expected that the very best of those vessels would be capable of staying to fight, on anything like an equal chance, a vessel built specially for the purpose of fighting, a vessel such as the "Tage" or the "Dupuy de Lôme" or the "Cecile"? Why had those vessels been developed in the French Navy? why had the armour-clad construction of the French Navy been almost standing at pause, while money had been spent and every effort urged on to complete such vessels as those? Simply because, as was perfectly well known, it was no breach of official confidence, for it could be read in the French newspapers, the idea which the French authorities had in their mind was to use those vessels, in time of war, to destroy English commerce and the mercantile marine. How were they to be met, if in the English Navy there were not to be found vessels equally fit to fight and certain to overpower the French vessels, if they met them? How was that to be done, unless the English also constructed large and swift cruisers powerfully armed? The Author had referred to the fact that cruisers of 9,000 tons were being built for the Royal Navy. He thought the country had good reason to rejoice that that was the fact. The vessels now being built, the "Blake" and the "Blenheim," if they fulfilled the intentions of the design, would be superior in speed, in coal, endurance, and in fighting qualities, to any vessels existing in the French Navy, and surely such a fact as that was one which justified their existence. Then as to their being so large, he could not help saying, that he thought the Author knew why they had become so large, why the "Blake" was a vessel of 9,000 tons? Because it steamed 22 knots an hour and had a weight exceeding 1,800 tons assigned to coal and disposable weight, independently of armament and equipment. The load of protection, armament, equipment and coal closely approached 4,000 tons. If the Admiralty were content to give up speed, if it were content to let vessels that were being built abroad run the chance of being met by a vessel that could not catch them, then it could reduce size and save money; not a saving to the country on the whole perhaps, but a saving in one direction. **Mr. White.** Passing from those somewhat controversial matters, he would refer to a subject which was strictly germane to the Paper, and in which he happened to have a special interest, and certainly some special information; he referred to the subject of the manufacture of armour, and to what had been lately done in this country in the development both of steel-faced armour and steel armour. Nearly three years ago he was informed in the public press that he was an obstructive. That was not the first time, but it then happened that he was again declared to be an obstructive. The subject was armour, and he was obstructive because he was said to be still recommending to the Admiralty the continued use of steel-faced armour, and was blindly shutting his eyes to the magnificent results which were being produced at Creusot. Safety was only to be had by giving orders for armour to the establishment at Creusot. English steel-makers had been left behind, and the French were head and shoulders above them. But he believed that if English steel-makers were given a chance they would prove that their hands had not lost their cunning, and that in England armour could be produced, whatever it might be made of, that should be as good as any made abroad. He was glad to say that the view he then put forward was approved by the Admiralty, with the result that a series of experiments had been undertaken that had been in progress for more than two years, and had proved that England could produce steel armour as good as any produced abroad—he believed better—and steel-faced armour, which was one of the grandest defences a ship could have. The Author had alluded to those experiments, and particularly to the experiments made against the armour-plates supplied by firms at Sheffield whose reputation had been made in that branch of manufacture, firms which had done good work for the Navy, and had given as honest and true a defence as was possessed by any war-ships afloat. The Admiralty had not only obtained from Messrs. Cammel and Messrs. Brown splendid specimens of steel-faced armour to be used as standards, but those very firms had made steel armour of great excellence; and firms like Messrs. Vickers had produced steel armour in many respects of a marvellous quality. This showed clearly that if the need arose for reinforcing the possibilities of the recognized armour-plate Sheffield firms, the necessary resources were to be found in this country without going abroad. The question was not any longer one as between steel-faced and steel armour. Steel-faced armour in the trials had behaved magnificently. The trials had justified their practice up to date, and it was now

r. White. known that steel armour as well as steel-faced armour could be used, and the most splendid results obtained. Those plates had been fired at with projectiles made in France, and he did not know why, if the defence could be so satisfactorily accomplished, English firms should not also make the means of attack.

r Frederick bel. Sir FREDERICK ABEL said it might seem to be the climax of presumption for a chemist to take part in such a discussion, but perhaps there might be some little appropriateness in the remarks of the Chief Constructor of Her Majesty's ships being followed by some observations from one who had taken some considerable part in developing agents for the destruction of ships, and it was from that point of view only that he desired to say a few words, some of which would be words of friendly criticism. With reference to the point in which he took the most interest, namely, the effect of shells against armour-clad ships, he confessed he came to the conclusion that a naval man, in reading the Paper, must be somewhat puzzled as to what he was to expect from the effects of the so-called high explosives against those ships. The Author had stated (p. 9) that after the Italians had made some experiments with gun-cotton shells, " English artillerists were endeavouring to perfect a delayed-action fuze, so as to delay the bursting of the shell containing high explosives until after the armour had been perforated. Since then every Government appears to have had experience, at the proof butts, of the difficulty of making a trustworthy controllable fuze for this purpose." He then went on to say, " When this fuze has been established, shells charged with high explosives will come under control, because bellite and lyddite appear to be in themselves perfectly manageable." He further stated that " The French authorities have satisfied themselves that they have brought melinite under control. The introduction of 4-inch side-armour over the batteries proves this." In looking for the proof he found it stated further on that "it has been ascertained that a delayed-action fuze is not at present procurable, and that the shock caused by 4-inch armour will explode shells with high explosives, fired from moderate-sized guns, on striking." Then it was stated (p. 11) that " Experiments have hitherto indicated the certainty that armour will be blown in by charges exploded against it, and that bursting charges with high explosives will be carried through armour probably 12 or 14 inches thick." Those statements appeared to him to be hardly reconcileable, and he should be glad to hear what the Author had to bring forward in the way of facts as to how they could be reconciled. He might state it as a fact, however, that delayed-action fuzes were no longer a matter of

Sir Frederick Abel.

theory—they had been actually developed. More than one thoroughly reliable delayed-action fuze was now attainable; and, if the effective application of high explosives depended only upon the provision of a thoroughly reliable fuze of that nature, the naval officer might depend upon having, in the next war, high explosives brought with perfect efficiency to bear even against thick armour. But it was known, on the other hand, that the provision of such a fuze was not the only element in the successful application of high explosives to the destruction or penetration of armour-clad ships. The Author had pointed out that 4-inch plates would cause the explosion of high explosives when thrown against a ship in the form of armour-piercing projectiles. It was true that he stated in another place that they would be carried through 13 or 14 inches of armour; but, as a matter of fact, it had been shown that 4 inches of armour could cause the explosion of armour-piercing shells containing high explosives. He would venture, however, to caution constructors, as well as naval officers, against drawing too rash a conclusion from that fact. It had been already proved by experiments that 4 inches of armour would not always keep out high explosives—that such armour could be penetrated by armour-piercing projectiles which would carry the explosive charge through. Not only that, but still further progress had been made, and similar results were now obtained against 6-inch armour. Chemists were only on the threshold of the application of high explosives, and he ventured to think, therefore, that it would be necessary to exercise very considerable caution before laying down the rule that armour even exceeding 6 inches in thickness, whether steel-faced or steel, would of a certainty keep out high explosive shells.

Captain Orde Browne.

Captain Orde Browne said, a fact on which it had been very difficult to get information had been now stated, namely, that shells charged with high explosives might penetrate 6 inches of iron, and that it was desirable that vessels should be divided into two classes, battle-ships and cruisers. Did not the question consequently arise whether armour ought not to be treated in two different ways? A cruiser carried armour that might allow a high explosive to pass into the interior much more easily than a battle-ship, for it might probably be a long time before a high explosive could be got which would pass through 18 inches of armour such as the battle-ship carried. The cruiser, as he understood, was intended to carry on a fight only for a short time. He did not suppose it would be expected to engage a land fort, for example, under ordinary circumstances. There were cases in which a line-of-battle-ship might have to do that. He believed the Author ptain Orde rowne.

considered this to be a total misuse of ships, but such things would sometimes happen. If distinction were made between the two classes, did it not follow that a harder class of armour should be provided for the weaker ship in order to make sure that it should keep out or break up a shell with a high explosive under any circumstances? The first object with the cruiser was to be sure to preserve it from a shell with a high explosive entering inside and then bursting; and he believed that was to be done by hard armour, at the expense, no doubt, of what had never before been allowed in this country, namely, the plate breaking, and being held up to a certain extent by bolts behind. He had heard Mr. Vickers speaking of the two plates he had submitted for trial, one harder and the other softer, and saying that he did not know which was best. The question was, what for? If the plate had such a thickness that without doubt it would stop perforation, and that impact of shells was expected to happen again and again, then, of course, the softer the better. If a weak ship was to be exposed a short time, the great object was to make certain that no high explosive should get into the interior. Was it not worth while to allow armour to break to pieces, if it were thereby made certain that it would keep high explosives out? In this country it had been continually insisted that the back of the armour should be very soft, because, unless it was very soft, whatever theoretical power of extension as well as tenacity it had, it would not extend, but would break. The Admiralty had insisted upon its extending as much as possible, and upon its breaking as little as possible at the back, and the result had been that the plates had necessarily been soft at the back. He was, therefore, anxious that experiments should be made with a harder class of armour with a view to those thinner clad vessels which were now found to be open to the entrance of shells charged with high explosives.

Martell.

Mr. B. MARTELL said he merely rose to ask a question. The Author had made a statement (p. 19) which he thought, unless some further explanation were given, might be misleading. "The most successful plate," he said, "ever fired at in England or elsewhere, so far as the Author can learn, is shown in Figs. 5 and 6. It is a steel-faced plate, 10½ inches thick, manufactured, according to their process, by Charles Cammell and Co., and attacked by 6-inch forged steel shot of 100 lbs. weight, and having a muzzle velocity of 1,976 feet per second, and a striking energy of 2,723 foot-tons. The same firm manufactured, at the same time, a steel plate. Mr. Wilson says it is 'the first steel plate which has ever withstood such a severe test without breaking up,' and that certainly

Mr. Martell.

it has proved much superior to any plate manufactured at Creusot, which has been subjected to artillery fire." Seeing that the subject was of national importance, and that manufacturers had been devoting their enterprise and investing an enormous amount of money in perfecting the best steel armour-plates that could be produced, it was greatly to be regretted that the Author had not mentioned all the experiments, referred to by Mr. White, that had been made by the Admiralty, with plates manufactured by the various firms throughout the country. The plates manufactured by one steel manufacturer alone had been expatiated upon, while those produced by other manufacturers for the same purposes were not even referred to. Considering the high position occupied by the Author, it might almost be considered an act of injustice to those who had competed to find that no allusion had been made to their plates. He had seen official reports of the experiments, and he should like to ask whether the Author had seen any official report bearing on the subject, so as to be sure of the accuracy of his statements. In one of the reports allusion was made to a steel plate that had been experimented upon at the same time. Five shots had been fired at a 10½-inch plate by the French shells, to which Mr. White had referred. He shared Mr. White's surprise that the French should have been called upon to make shells to fire at English armour-plates. Two of the five shells were cast-iron, and they crumbled into pieces on striking the armour-plate; the other three, which were steel, made an indentation to a certain extent, but, to show the tenacity and the resistance of the armour-plate, they rebounded so that they struck the shot-guard some 20 feet distance, and rebounded back again to the steel armour-plate. He wanted to know why it was that no information had been given by the Author on that subject.

Mr. White.

Mr. W. H. White said that the question was not one which the Author could answer. The facts were simply these: The Admiralty, in entering upon the experiments, gave to each firm that submitted a plate the guarantee that it should be fired at under the same conditions, and that the firm should have the report on its own plate. Although Mr. Martell was no doubt accurate in his statement that he had seen a copy of one report, that would be owing to the action of the particular firm in question.

Mr. Martell.

Mr. B. Martell hoped the Author would use his influence to obtain a copy of the official report for the good of the country, in order that a proper comparison might be made of the experiments. When the manufacturers of the country were incurring such an enormous expense, and striving so much to arrive at the perfection

Martell. of armour-plating, everything should be done to encourage them, and at least put them on a fair footing with each other. When such statements were made as those put forward by the late Director of Naval Construction, they would have an enormous effect throughout the country, and would not, it was thought, appear fair to those who had entered into the competition.

Robbins. Mr. E. Robbins said he had come to the conclusion that, in order to meet all requirements, a new departure was essential. Instead of steel plates he had formed the idea of having interwoven bands, held on not so much by rivets as by an elastic binding concrete. The bands would be combined with wood and metal, and would form an elastic body which would throw off shot.

niral wyn. Admiral J. H. Selwyn remarked that the Paper appeared to touch almost every question known to naval architects and engineers who occupied themselves with ships or guns. He would not refer to all the points, but would only mention six in which he thought they were still behind in scientific work. There had been an enormous amount of rule-of-thumb work, which consisted in a system of trial and error on the large scale, and sufficient attention had not been paid to the scientific bases of action. It was now generally agreed that long-continued speed was an absolute necessity for all ships, and in order to get that (even more valuable for cruisers than for battle-ships) strong boilers were wanted. But were the boilers strong? An advance had been made during the last five or six years in compound engines, though, unfortunately, ship-owners had been persuaded that the essence of the whole was in the engine and not in the pressure on the boiler. He had known a high-pressure boiler, one of the much-abused boilers of the "Wanderer" on Mr. Perkins' principle, which had since been at work for eight years, day and night, at 350 lbs. pressure, which was tested at 2,000 lbs. on the square inch when made, and which was to-day capable of taking 500 lbs. pressure without injury. He considered that no proper boilers would be constructed as long as that part of the subject was not closely investigated. Without those high-pressure boilers neither a high economy nor a high speed could be attained. That high speed to be of value should not be produced by a puff of forced draught; it should be produced over a long time. To get that, the use of concentrated or fluid fuel was wanted. He had been long at work on that subject. He was delighted to see some progress in armour; but it had only proceeded from solid steel and solid iron to sandwiched steel and sandwiched iron. It had not proceeded on a well-defined scientific basis. He was glad the Author saw his way, if only money enough was given, to produce vessels which could not be sunk by shot, torpedo or ram. Sir Edward Reed asked the question whether it could be done with many torpedoes, many guns, and many-rams; and he did not think that that question had yet been answered. The nearest approach to it would be when the whole power of the engine could be devoted as well to pumping out the ship as to propulsion. Strong and far-reaching guns were also wanted. He had made it his business to look into the subject of wire guns, and a question had been asked in Parliament on the subject. Engineers, he thought, would be surprised to hear that so long ago as 1884, the Ordnance Select Committee[1] recommended a riband-gun as having demonstrated completely the durability and the reliability of the wire system for very high pressures; the guns having been made, not by Mr. Longridge, but by other persons after they had found out that the rule of thumb was of no good, and that his formulas were valuable. A wire-gun at Woolwich fired a shot 12½ miles without any injury, at an angle of 40°, and with a charge which was nearly double that which the 9-inch gun of the same calibre, a service-gun, could possibly have stood. Why that gun had not been brought forward he did not know. He believed that the system of wire-gun making would be brought forward some day as a commercial manufacture on account of its extraordinary cheapness and durability. No proper result would be obtained from strong guns without strong powder. So long as cubes of powder were used, many of which would not burn even after they got to the muzzle, and at night were seen burning afterwards, which also tended more to erode the gun than any gas, so long scientific principles would not be brought to bear on the question. With regard to the six points to which he had referred, everything that was desired could be done in respect to number one by Perkins' boilers; to number two, by concentrated fuel; to number three, by a scientific construction of armour; to number four, by hydraulic propulsion; to number five, by wire-guns; and to number six, by

Admiral Selwyn.

---

[1] The words of the O. S. C. were: "They do not propose to carry out any further firing trials with this gun with its present tube; and they are of opinion that this trial has shown that the system of wire construction is one suitable for heavy guns, and that it may be depended on to withstand very high pressures."—Reports of the O. S. C., vol. xxiii. p. 141, and Appendix III. This was on the 31st of Oct., 1884; but the inventor of the wire-gun system was not informed of the conclusion, nor had he even now received any recognition, neither did any report show what eventually became of this particular 21-ton 10-inch gun except that it had a new tube and was fired again, and it was known that wire-guns were still being experimented with.

Admiral Selwyn. perfect combustion, as Colonel Brackenbury had called it, of "the spirit of artillery or good, strong, gunpowder." With reference to the subject of armour-plating, the Author had stated that Mr. Alexander Wilson was the inventor of compound armour. In 1870, Admiral Selwyn first drew the attention of naval architects to the construction of armour on the analogy of the anvil. He did not know whether sandwiched armour might or might not have been invented before, but sandwiched armour never could do what properly constructed armour would do. He was not ambitious of claiming priority of invention in compound armour as now made; but he maintained that a most important investigation was now possible, based on experiments which had given a cone of dispersion that had sufficed to spread the impact of perhaps 9 or 10 inches diameter over a diameter of 48 inches, making a bulge at the back of the plate 2 inches deep which had crushed up the oak behind it, but so spread the number of tons force received on the point of impact over a larger area of 48 inches in diameter, instead of 9 inches or as 63·6 to 1,809·6 square inches, as to bring it down to not much more than 7 tons on the square inch on the oak backing of the armour. That was a magnificent result; but the plate cracked in consequence of its not being properly proportioned, and what he urged on the engineers was the question whether the most important molecular movement of the steel particles was not more valuable than any great thickness of steel face, or of wrought-iron backing. The plates now made by Sir John Brown were, according to the Ordnance Select Committee, a little different from what the Author had described, being made by wedging, 4½ inches from the back of a 16-inch plate, a steel face supported partly round three sides, and pouring the cast metal in between the two from above. That cast metal had been brought to such a heat that it united both with the steel face and with the wrought-iron back, and the result on its being fired at with a Holtzer or Firminy armour-piercing shot was such a cone of dispersion as he had mentioned; and which ought to show one of two things—either the steel particles had separated from each other entirely in their descent through an average of 2 inches over 48 inches of diameter, or they were in perfect cohesion. In one case, the steel could be no longer steel, but powder; and, in the other, it would be evident that great molecular movement could take place amongst the steel particles without disruption, and a great absorption of force, or "shot work," in that manner be obtained, making it possible to have much stronger armour with much less weight, and probably at considerably less expense.

Admiral Sir G. Elliot.

Admiral Sir GEORGE ELLIOT was a supporter of the views of the Author to a large extent. He did not propose to dilate on the subject of the Papers that had been written, but would content himself with offering a few remarks, from a tactical point of view, with regard to the character of this new design. He considered it a most valuable novelty in the designs of ships of war, and one upon which the efficiency of the future fleet of the country, and indeed the safety of the Empire, depended. He looked upon the question of a battle-ship solely from the point of view of a great fleet action. If any attempts were made to depart from that view, and it was endeavoured to give a battle-ship other qualities, its fighting efficiency would be to a certain extent lost, and the battle would be therefore hazarded when it arrived. The object should be to gain a victory. The fate of the empire would probably depend upon the result of some great fleet action, and not upon fights between squadrons. Decisive battles would be fought, not between two different powers, one of which was striving to run away, but between two powers that had come out on purpose to fight. That had always been the case, and it ever would be. So far, therefore, he differed from the Author, although he quite understood that he had been pressed into giving his ship the speed he had given. A battle-ship did not require a 17-knot speed, a 14-knot speed was ample; it would give a certainty of a 10-knot speed in battle. That was all that was required, and all speed given beyond that was so much loss in fighting power, and so much risk of losing the battle when it took place. The new 14,000-ton ships were designed for 17 or 18-knot speed, but if they were built for 14-knot speed they would have a far greater armour protection, and far greater safety and efficiency in battle. It was said that great speed was required in case the enemy, when sighted, should try to run away. In olden times, when an enemy was sighted, the frigates were let loose like greyhounds, to attack the rearmost ships of the fleet and bring on an action, and owing to many causes there would always be sluggish ships in every steam fleet. Nowadays cruisers should be made as swift and powerful as possible, and he, for one, should not object to see the first-class cruiser with 14,000 tons displacement, because battles between single ships or small squadrons would always be fights in which the gun would predominate, and in which the ship could escape from the ram and torpedo. The Author had spoken of unarmoured ships being combined with a battle-fleet, and therefore having to run the same risks as the battle-ships. He denied that altogether. The cruisers that would be attached to iral Sir C. ot. the fleet would form a separate squadron, like frigates of old, and would be kept out of action until the opportunity occurred for their coming and rendering assistance, probably to the crippled ships of their own country; but they would not be placed in the line of battle. It was impossible to go into this question, which was a very large one, as fully as it ought to be dealt with, without trespassing too far on the patience of the meeting, and he would confine his remarks to those which he could perhaps best offer as a tactician. The whole question was, whether the gun-power was to be concentrated in one vessel, or divided between a number of vessels, thereby multiplying the units of a fleet, and reducing the risk of great disaster? He was not prepared to say that he would now hold to the size of the ship that had been brought forward; but, taking the ship altogether, he thought the Author had done everything in his power for a ship of that size. For himself, he should be inclined, for reasons that he would state, to advocate a vessel of twice the displacement, as the limit of the size of the battle-ship of the future. In that way he would have two ships of 7,000 or 9,000 tons for one that the Admiralty was going to build of 14,000 tons. That would enable him to make the protective deck sufficiently thick to ensure safety to the magazines and boilers. The vessel should be of deep draught, in order that the armoured deck should be as horizontal as possible. If the vessel was of shallow draught, height being required for the engines, a turtle deck became necessary, thus making it more easily penetrable by shell. He should like to see a 6-inch steel deck horizontal, which would prevent the penetration of any shot from any gun that was carried. The great fault that he had to find with the Admiralty design was the want of recognition of the destructive effects in a fleet action of the ram and torpedo. He believed that in the first great battle at sea more ships would be destroyed by the ram and the torpedo than by the gun. It had been so customary to look to the gun as the ruling power that that idea was not readily given up; but he thought that, when officers were called upon to report upon the nature of the battle likely to be fought, they should have before them a plan of campaign, and also come to some decision as to the character of the fighting of the future. On those points he did not think that any settled plan had been determined. The whole thing depended upon the future mode of fighting. Was it to be as formerly, in line of battle, in close order in one, two, or three lines? If that was the case he could only say that the prospects of destruction from the ram and torpedo were far greater

Admiral Sir G. Elliot.

than could be expected from the gun. Taking into consideration the number of ships that would be brought together in close contact, it appeared to him to be impossible that they could escape the torpedo. It was said that the torpedo was erratic, and did not go straight. Torpedoes, however, would be cruising about in the middle of the fleet in one direction or another. It was said that they might hit the friend as well as the foe, but still the danger existed. There would, he imagined, be two torpedo gun-boats attached to every battle-ship that went into action, besides the torpedoes which the ship carried, and he did not see how it would be possible to escape them. The ship might not be sunk, but one blow would open a compartment and let in a sufficient quantity of water to put it out of trim, and then, being disabled, it would be at the mercy of the nearest opponent. The Admiralty had not recognized the destructive effect of the ram. The best proof of that was that the bows of all the ships were unarmoured. The bow of every French ship was armoured. If two fleets met, and one had stronger bows than the other, the ships with the strongest bows would have the advantage. They might not strike end on, but they would hit the bow somewhere, and the strongest would come off best. The shorter and the handier ship would have the opportunity of planting its spur on to the bow of the other. If there was the smallest oblique angle of the ram on the bow, there was at once an advantage; the handier ship would have that advantage; and that point had not been sufficiently recognized. It was stated that the Russians were going to build enormous armour-clads; he only hoped they would do so. He did not know what their size was to be, but his belief was that other nations would try and multiply their torpedo boats, and their smaller vessels, and trust more in the future to the ram and torpedo than to the gun. In his opinion the days were gone by for big ships, big guns, and side armour. He held that opinion twenty years ago, and had not altered it. It was said that officers in the future would not have the pluck to ram. History did not record that French officers were wanting in pluck, and he believed what an old and distinguished officer had said to him, that the great work in future in naval battles would be ramming. If so, the proposed monster ships would be a decided mistake. The bigger the ship, the more easily it would be rammed, and the same blow would disable a big ship as would disable a smaller one. When it was said that the smaller vessels would be destroyed in detail, it was forgotten that those smaller vessels would all the time be endeavouring to undermine those enormous citadels lmiral Sir G. liot. with whom they were opposed. With regard to the raft body, he believed, as the side armour was penetrable, that this mode of protection would be far the safest, as a ship would have to be very much riddled before water enough would be let in to disable it; but let one shell or shot go through the armour into a large compartment, or reach the magazine or boilers, and the vessel would be at once totally disabled. He would only add that every ship intended to ram should be armour-clad round the bow, with struts across so as to support the armour. In that case the vessel, if it rammed another, would not, as had hitherto been the case, do itself as much injury as the vessel it struck.

r.Nordenfelt. Mr. T. NORDENFELT said he thought the Author was quite right in laying stress upon the cost of ships of war, because if the nation could afford to build very large and powerful ships very heavily armed with heavy guns, and could send them out to fight the sea-battles referred to by Admiral Sir George Elliot, it would be able to hold its own on the seas, and would have a distinct and decided advantage over powers who could not afford it. He thought a fleet of eight 14,000-ton ships was a grand and admirable thing. It might be expensive, but it might carry the day in battle. Some of them might be lost; but the others might gain the victory. Mr. White had very carefully and cautiously said that such vessels as had been recommended by the Author might even find room in the British Navy. Those words "might even," however, did not apply to foreign nations. When they had adopted it, perhaps the British might follow suit. With many foreign nations it was a necessity that the ship should be able to carry heavy guns. Some of them could not afford to build heavy armed ships. England, besides the grand nucleus of 14,000-ton ships, required also a large number of ships which could carry heavy guns for the purpose of the very many points of defence that were necessary. Even England, however, could not afford to have 14,000-ton ships at all the out-stations, coal-stations, and depots; but needed guns powerful enough to penetrate other ships that might be met with at those stations. About ten years ago he remembered that a smile spread over the faces of some of the authorities at the Admiralty when the Italians commenced their eight large ships, beginning with the "Duilio" and ending with the "Umberto"; but even to-day those ships would give them the chance of doing enormous damage at sea, and they might live somewhat longer than their opponents. The word "battle-ship" was, he thought, somewhat limited in the meaning set upon it by naval men. It was nowadays difficult to know what a battle-ship meant.

Mr. Nordenfelt. The new cruisers of the Mersey class, carrying 9·2-inch guns, 22 tons, had to do battle for their country like every other ship, and they would no doubt join in a big battle; indeed they could not be kept out of it. Most of the smaller cruisers had no protection except the steel deck against vertical fire, or against the explosion of shells. The great object of the Paper, as he understood it, was to advocate a ship, something between the cruiser, so called, with a steel deck, and an armoured ship. He had made a ship which protected the guns, the gunners and officers, the machinery, and all the vital parts. Mr. Nordenfelt's view of it was that it was a gun-carriage—a means of supporting and carrying guns swiftly enough to overtake large ironclads, even if not swiftly enough to escape cruisers. But it was not wanted to escape cruisers; they had big guns and armoured turrets, and the object was to catch them; and he thought that a speed of 17 knots an hour was perfectly sufficient for what he might call a mobile gun-carriage. The Author had said that such ships could meet an ironclad if they were four to one. If there were four ships carrying 9-inch guns or other guns, and if they could, from being handy, choose their position of attack against the big ship, even if one or two of the smaller ships were lost, the big ship would probably be disabled before the other smaller ships were lost. It had lately been proposed by a foreign nation to have ships of the type recommended by the Author with 6-inch quick-firing guns, two on each ship in action at the same time, and all capable of an all-round fire. With four ships capable of more speed than the big ironclad to be attacked, each ship having always two quick-firing guns in action, that meant a firing power of from fifty to seventy shots per minute, each shot being a 100-lb. shell containing a high explosive, thus giving from 2 to 3 tons of shell-metal fired during each minute against the ironclad. What would an ironclad with a very large percentage of its surface unprotected look like in a few minutes after such an attack? It could only fire with its big guns one shot every two or three minutes, in addition to the fire from the auxiliary armament. He would rather fight on board one of the smaller vessels than on the big one. Time was a very important element in work of that kind. He had had the honour of being the first man to introduce into this country officially the system of quick-firing guns, and had in fact given them the name "quick-firing guns," and he believed that such guns had to a great extent revolutionized naval construction. But it was easy to go too far, and to put too much weight in armour. Sir Frederick Abel had spoken with reserve about high explosives, but Mr.

Mr. Nordenfelt. **Nordenfelt** thought that Sir Frederick could have told the meeting that it was a fallacy to suppose that any plates of 4 inches must necessarily cause on the outside an explosion of high explosives. If a high-explosive shell could not to-day penetrate 4-inch or 5-inch plates, it would do so to-morrow, and long before the ships were ready. Field artillery, cavalry, and infantry, attacked the enemy without any protection whatever, because if they had protection they would lose their mobility. And it was the same at sea. Fortifications, temporary and fixed, were wanted ashore. Big ironclads were needed, no doubt, in the same way for resisting the fire of the enemy. But there was room also for other ships, and he was perfectly certain that gallant sailors would prefer to feel that they were on board a floating gun-carriage which gave them an enormous power of attack, rather than be in another kind of carriage in which the defence was more studied than the attack, and in which they had to be protected by thick armour for a time. No protection was perfect. If a shell hit a big ironclad when it happened to heel over so as to admit the shell below the armour, it would be most seriously injured, and a ram of a torpedo might sink it. The protection could not be perfect, and he therefore preferred the means of powerful attack to the means of protection. He wished to say one word on the subject of armour plates. Captain Orde Browne had said that it was understood to be necessary for the armour plate that it should have a part of it, the hinder part, which would hold together the pieces in front, when the front pieces resisted the attack of the shells. No doubt that was so at the time. Mr. Alexander Wilson did a great deal of good by his patent for compound armour in days when there was a want of experience in steel making. The solid steel plates made at the Creusot works, by Mr. Martell and by others, were very brittle, flew to pieces and laid bare the side of the ship, and Messrs. Cammell and Messrs. Brown had benefited the various Navies during the last decennium in enabling them to use armour of which the front part resisted shells, the hind part welding the pieces together. If steel makers had succeeded in making solid steel plates of such a quality that they not only resisted the shells sufficiently, but were able to hang together, surely that was better and safer than the older plates. He admitted that compound plates could be made harder at the surface, and consequently tend to break up the shells, but shells were now made that did not break up even when fired at a sharp angle. What was wanted was the thickness of solid steel with a sufficient percentage of carbon to resist penetration. Some remarkable results were exhibited in the photographs of plates made by Mr. Vickers. If such solid steel plates could be made in large quantities, they would be more useful than the plates which had not so complete a resistance. He liked formerly a hard steel face, even if it were shattered in breaking up the shell, because it was not likely that two shots would hit in the same place. But still better than that was a plate which did not let the shot pass through, and which did not fall off when struck. Admiral Howard had spoken of the advantage of small ships in comparison with large ironclads, and he had mentioned one point that could not be too much dwelt upon, namely, that there were four brains and four captains to take charge of the same power or the same money that was placed under the charge of one man in a larger ship. Another officer had spoken about splitting the brains into four; but that was not the point. The point was the question whether the power of the single brain could deal with the responsibility and the many complicated questions that continually arose, when commanding a ship of war, or whether the intelligence and experience of four captains of ships would not be preferable. **Mr. Nordenfelt.**

Mr. T. E. Vickers wished to refer to the question of the material of which armour-plates should be made. He submitted for inspection photographs of two solid steel plates, which had been tried in the recent series of experiments made by the Admiralty, and alluded to in the Paper. The plates were all 8 feet by 6 feet by 10½ inches thick, and were tested on board H.M.S. "Nettle," at Portsmouth. The gun used was a 6-inch gun charged with 48 lbs. of powder and 100-lb. projectile. The plates were supported in a framework against wood backing, which represented the side of a ship. The gun was placed at a distance of 30 feet from the plate. Photographs were taken of the plate before being fired at, and after each shot was fired; and any fine cracks were marked with chalk, so as to be seen plainly on the photographs. Afterwards the back of the plate and the wood backing were photographed, in order to show to what extent the plate had answered its purpose in protecting the ship. The steel projectiles were also photographed. Five rounds were fired at each plate; the projectiles used for the first, second, and fifth rounds were the well-known Holtzer steel armour-piercing shells; at the third and fourth rounds ordinary Palliser chilled-iron shots were used. The first of the two plates was delivered to the Government before the steel plate of Messrs. Cammell, mentioned in the Paper, but was tested after it. The three Holtzer shots, after penetrating the plate to a considerable depth, rebounded against the bulkhead through which the muzzle **Mr. Vickers.**

Mr. Vickers. of the gun protruded, and the Palliser shots were broken into small pieces. The throwing back of the steel shots was unprecedented, as far as English experiments were concerned. The second plate was made at a later date, in order to see if the good results at the first trial could be repeated. Advantage was taken of this second trial to try if a somewhat harder plate would give a better result. This plate was penetrated to a less depth than the preceding one, and the Holtzer shots were thrown back with greater force, and were also broken; the plate itself was rather more cracked than the first one, but not seriously so. The whole of the plate remained in position, although one corner was found separated when the plate was removed. The second plate was fired at on a frosty day, and it was possible, if not probable, that the increased cracking was due to the lower temperature. The conclusion he derived from these experiments was, that the hard nature of the steel, which could be used in the front portion of the compound plate, gave a better resistance to the projectiles than the first portion of the steel one did; but that this advantage was lost by the comparatively feeble resistance of the iron portion behind it. The steel plate continued its resistance to the last, as shown by the fact that the steel projectiles rebounded with considerable energy. He believed that in thicker plates the advantages of steel would be still more marked.

Barnaby. Mr. SYDNEY W. BARNABY said he proposed to address his remarks not to armour, but to that part of the Paper which was to him of greater interest, namely, the new material introduced by the Author as a substitute for armour at the region of the water-line. It was astonishing to learn that, with an appropriation of 5 per cent. of the displacement of a vessel, a solid belt of that material could be placed at the water-line, which would exclude 96 per cent. of the water that would otherwise enter through perforations at that region. The Author had shown how he would use that material for the protection of an armoured ship of war. He had listened with much interest to the criticisms which had been passed upon that design, and he thought they might be summed up in this, that the ship was small. Every naval architect would agree that there was no fault in a design which was more easy to remedy than smallness. If the only fault that could be found with a man was that he was too young for his post, the obvious answer was that he would grow out of it. In like manner, if the severest stricture upon a design was that it was too small, the obvious answer was that it was easy to enlarge it. If the Author were told that more coal was wanted in the ship, he would say, "It will take so many more tons displacement; I can do it." If he were told that it was **Mr. Barnaby.** necessary to increase the auxiliary armament, he would again reply, "It will take so many more tons, but it can be done." But in the case of a ship of 14,000 tons displacement, when the critic began by saying that the ship was much too large, then that there was not half enough coal, and then that certain portions of the ship were coated with 5 inches of armour where there ought to be 15 inches; in order to satisfy him it would be necessary to take a clean sheet of paper, and begin the design over again. The Author had alluded to the Admiralty policy of taking up merchant cruisers, and using them as fighting ships. He had stated elsewhere that it was quite possible to build such ships with their machinery below a bomb-proof deck, in which case they would be as easily defensible as a regular ship of war. It appeared to him that if such ships were built like the present Atlantic liners, but with their machinery covered by a 1½-inch deck and with the new material stowed between the protective deck and another thin deck 2 feet above it, as in the Author's design of a war-vessel, such a ship would be as well defended as a cruiser of the "Tage" type; and he would ask the Author whether he did not think that it might be wise for the Admiralty to build such ships protected in that way, and that, instead of hiring inefficient war cruisers from the merchant navy, it might let out these vessels to the shipowners for trading purposes. Of course the packing material would not be put in until the ships were required to fight, and the space occupied by it would be available for cargo. All that the owner would have to put up with would be a certain permanent load imposed by the protective deck, and a large engine-room staff, because two or even three screws would probably be required in order to keep the engines below this deck. The gain to the country would be twofold, first, the present fast ships, which, it should be remembered, were the only vessels which had a chance of running the gauntlet of hostile cruisers and bringing in the food supply, would not be withdrawn from the trade routes at the very time when they would be most useful. Secondly, very efficient war-cruisers might be made self-supporting, or even a source of profit to the nation, instead of a constant drain upon its resources.

Dr. W. Pole, Honorary Secretary, while fully admitting the **Dr. Pole.** great public importance of the design of armoured ships generally, remarked that the branch of the subject which most nearly concerned engineers was the construction of the armour, and its mechanical efficiency in affording protection. The Author of the Paper, though he had given some particulars, had said but little on this head, and it was somewhat surprising to find that, although for thirty years the subject had been so prominent as a national question, it had come so little before the Institution. The nature of the material to be used, its mode of manufacture, the design, form and dimensions of the armour, the manner and amount of its resistance to shot and shell, the connections and fastenings, and many other points, were all questions purely belonging to the civil engineer; but, strangely enough, there was scarcely a reference to them in the whole of the Minutes of Proceedings. The Government had, however, thought it expedient from time to time to call in the services of engineers to their aid, and as Dr. Pole happened, at an important time, to have taken an active part in this way, he would ask leave to put on record some account of what had then been done. The Author had alluded to the early opinions authoritatively given, about 1850, by British naval authorities, against the use of iron for naval war purposes. But the French were not so hasty, for a year or two afterwards, at the outset of the Crimean War, the French Emperor suggested the use of thick plates of hammered iron as a protection to floating batteries, which it was proposed to use in attacking Cronstadt, and an experiment was made in 1854 at Portsmouth by firing at a 4½-inch plate with wood backing. The result of this was that three such batteries were ordered by the French Government and an equal number by the English. When the time came for their use, the British batteries were not ready, but the French ones were, and they were employed in the attack on Kinburn on the 17th of October, 1855. They were exposed to a heavy fire, at a distance of 700 yards, for about three hours, unsupported by the fleet, and at the end they came out practically uninjured. Such a test as this was conclusive; and from that date the utility of iron armour in protecting ships of war became an accomplished fact. The French lost no time in carrying the idea further, for they at once began building a large sea-going ship of war, of 5,500 tons, protected on this principle. This vessel, now become classical under the name "La Gloire," was launched in 1860, and was clothed from end to end in exposed parts with iron armour, some of it nearly 5 inches thick. Meanwhile, the Kinburn success had gone far to dispose of the prejudices of the British dockyards, and the question of the claims of iron was re-opened by several experiments made at Portsmouth and at Woolwich, in 1856–1857, and 1858, with iron structures of various kinds. And, moreover, as the Government could not allow the French to steal a march upon it by the new-fashioned armour-clad man-of-war, it was decided to keep pace with them by constructing a similar ship, protected in the same way. This was Dr. Pole. the "Warrior," a fine steamer of 9,200 tons, which was launched in 1861. But, when the application of iron armour began to be seriously entertained, the Government found that it involved a multitude of questions, chiefly of an engineering character, which required the most careful and patient investigation, and it wisely decided that the whole subject should at once be submitted to a Scientific Committee, on which the engineering profession should be represented. This body, which afterwards became well known as the "Iron armour-plate Committee," was appointed by Mr. Secretary (afterwards Lord) Herbert, in January 1861, and it consisted of six members, namely, Captain Dalrymple Hay, R.N. (Chairman), Major Jervois, R.E., Brevet-Colonel W. Henderson, R.A., Dr. Percy, W. Fairbairn, and Dr. Pole. The Members of the Committee were in active work till the middle of 1864; they reported frequently and fully their proceedings to the Government, and their reports were printed in four folio volumes, with full illustrative plates.[1] These documents were withheld from publication at the time for reasons of public policy; but after this interval there could be no impropriety in giving to the Institution a brief account of their proceedings, and of the results that followed therefrom.

The object intrusted to them was to investigate generally the application of iron to defensive purposes in war. Their first duty was to make themselves acquainted with the knowledge already existing on the subject, and this they did in two ways. In the first place, they collected and reported on all the records they could find of previous experiments or investigations. These led to a general belief that iron was capable of forming a good protection, but still very little useful practical knowledge had been acquired either as to the quality of material most efficient for the purpose, or the most advantageous mode in which it should be applied. The next step was to learn the views held on the subject by those persons best acquainted with it, and the Committee accordingly invited the evidence of a great number of scientific and mechanical men who were likely to possess knowledge bearing on the subject. Among the witnesses were Sir William Armstrong, Sir Joseph Whitworth, General Lefroy, Captain Andrew Noble, Mr. C. W. Lancaster, and Mr. John Anderson, as eminent authorities on modern artillery; Mr. Scott Russell, Mr. Laird, Mr. Samuda, Mr. John Grantham, and Captain Hewlett, on naval construction; Professor Wheatstone, Mr.

---

[1] Transactions and Report of the Special Committee on Iron.

Pole. Mallet, Mr. Nasmyth, Captain Inglis, on the general scientific and mechanical treatment of the question; and all the most eminent iron manufacturers in the kingdom, as to the properties of the material. The information given by these witnesses was extremely valuable, but their opinions were very conflicting on the novel points before the Committee. Having thus obtained all the information possible, the Committee began its own more special labours, and these consisted of original investigations, chiefly of a practical and experimental character, which were directed to two classes of objects, viz., first to the determination of a great number of points affecting the general application of iron for defensive purposes, and secondly, to the direct trial, by ordnance, of special constructions, in the shape of targets designed and prepared for the purpose. The first and most important point was the nature of the material best adapted to resist the impact of shot. On this there was little positive knowledge, and the witnesses held great diversity of opinion. Some recommended soft and tough iron; others, steel of different kinds, and others combinations of steel and iron. The Committee tried an extensive series of experiments. which led to the conclusion that the most suitable material was simple malleable iron, the best kind being that which combined in the greatest degree the qualities of softness and toughness. It appeared that the use of defensive armour-plates against shot, was to resist the blow in such a way as would do the least mischief to the structure, and that the best mode of accomplishing this would be to make the plates of soft, tough material, which would allow the "work" residing in the shot to be absorbed in indenting and battering them, without producing their fracture. The Committee directed much attention to the mode of manufacture of armour-plates. This, at the commencement of its labours, was quite a new thing, as no masses of malleable iron of such magnitude had previously been made. The first plates were made by hammering, but powerful machinery was soon erected for rolling them, and the rolling proved preferable for obtaining the quality required. The Committee gave every encouragement and stimulus to the makers to improve their manufacture as much as possible. With this view the plan was adopted of inviting them to see the experiments, and to study carefully the effect of shot on plates, giving them at the same time the benefit of all available information which could throw light on the subject. These opportunities were of the greatest use, for by no other means whatever could any such complete insight have been obtained into the nature of the problems to be solved, and the conditions necessary for their solution; and further, this system of openness gave universal satisfaction to the trade. The ironmakers availed themselves willingly of the facilities afforded them, and the result was, that whereas, at the appointment of the Committee there were very few ironmasters who could make thick armour-plates, and those of very uncertain quality, there were at the end of the Committee's labours many excellent makers, the dimensions had much increased, and the quality had immensely improved. At first the Committee could scarcely rely on the quality of any plates above 3 inches thick; afterwards 5 and 5½ inches became common thicknesses of approved quality, and some of the best samples were thicker still. The chemical composition of the various irons was accurately determined, and various metallurgical data were obtained. Careful comparisons were made with foreign irons, and it was fortunately found that armour-plates could be made with iron obtained from British ores, by the ordinary processes of smelting, and manufactured with mineral fuel, not only equal, but superior to foreign plates of much more costly production. Another very important point of the Committee's inquiry, was the form in which iron could most favourably and economically be used for defensive purposes. Various opinions were held on the subject: some authorities recommended a peculiar arrangement of bars, which previous experiments had favoured; certain eminent engineers and shipbuilders suggested a number of thin plates, well fastened together, a form which was thought to present great advantages for naval purposes, in affording support to the structure and at the same time offering great facility and economy of construction; while a great number of other schemes for bent plates, corrugations, ribs, bosses, and many other ingenious contrivances had their supposed advantages strongly urged. More than four hundred plans were submitted to the Committee; these were all examined and reported on, and some of them were tried; but through all these complications the simple result was arrived at, that the best application was a single plate of uniform thickness, with the surface perfectly plane. It was found that a large size of plate was advantageous as giving fewer joints, although small plates were more trustworthy in quality, as well as much cheaper. At first it was supposed to be an advantage to connect the edges of adjoining plates by grooving and tonguing, and this was done in the "Warrior;" but it was shown to be a mistake, doing mischief instead of good, and was therefore abandoned. Another point of great uncertainty was as to the best mode of fastening armour-plates to the ship's side. Numberless schemes were devised for doing away with bolts passing through the plate; Dr. Pole.

but experience showed that, with certain precautions, bolts and nuts were perfectly efficient. One of the latest experiments, however, gave remarkably good results with the French plan of large wood-screws holding into the backing behind. Great interest attached to the question of the backing most suitable for ship armour-plates. When these were first used, they were fixed directly upon the hull of timber ships; and, when they were first applied to iron ships (in the case of the "Warrior"), it was thought expedient to imitate the former condition, by placing a thick layer of wood between the armour-plate and the skin of the vessel. Many objections were raised to this; the wood backing was said not only to be unnecessary, but to be absolutely prejudicial, as liable to decay, and to destruction by fire and by shells. It was necessary that the Committee should thoroughly test this, and elaborate experiments were designed and carried out for this purpose; but the Committee was unable to recommend that this wood backing should be dispensed with, as it appeared to perform important functions for which no thoroughly efficient substitute could be found. The nature of the projectiles was a subject intimately connected with the resistance of the plates, and a great number of experiments were made, in conjunction with the Ordnance Select Committee, to determine the influence of variations in the weight, velocity, form, and material of the projectiles as regarded their effect on the armour. Discussions of the results obtained were given in two memoranda by Dr. Pole in January, 1862, and January, 1863.

In addition, however, to the determination of general principles, it was the duty of the Committee to make trials of actual structures on the largest scale, for it was impossible to tell, by any *à priori* reasoning, or by any deductions from small trials, how the armour of ships would behave under fire. The Committee remarked:—

> "One of the most striking deductions from our experiments is the difficulty, even for those most conversant with the subject, to foretell what are likely to be the results of untried schemes, however promising they may appear. The effect, upon iron structures, of heavy shot from modern ordnance, is totally unlike the result of any other kind of mechanical action, and has conditions essentially peculiar to itself; experiments, therefore, on a great scale are absolutely essential to determine the merits of many plans still awaiting trial."

It was, therefore, determined to make targets on the actual scale, representing portions of the sides of ships armed in particular ways, and to ascertain their value, in the most positive and unequivocal mode, by firing at them with heavy artillery to the point of complete destruction. One of the earliest of these was a target

Dr. Pole.

representing a portion of the "Warrior" frigate, which, as already stated, had been built somewhat hastily in emulation of the French ship "La Gloire." The target was 20 feet long by 10 feet high, and was composed of 4½-inch wrought-iron plates, bolted to a wood backing 18 inches thick, behind which was the iron skin, supported by wrought-iron ribs, exactly as in the ship itself. The target was fired at in October, 1861, with many rounds of shot and shell from the heaviest guns then available, at 200 yards range, 3,229 lbs. of projectiles striking the structure; and although, naturally, much damage was done, the resistance offered was considered very satisfactory. This same target was again tried, with heavier artillery than before, and the report was that no other target experimented on had offered so good a resistance. Many authorities considered, however, that it would be desirable to try other systems of protection, and accordingly several other targets were constructed embodying different ideas. Two of these were on plans by Sir John Hawkshaw, one by Sir William Fairbairn, one by Mr. Scott Russell, and one by Mr. Samuda, all which, under fire, gave valuable information of some kind or other. And as the building of armed ships went on, with modifications in their mode of protection, targets representing them were put to the proof; the "Minotaur," the "Lord Warden," the "Bellerophon," and others, being proved in this way. These and other ships were built expressly to carry out the designs drawn from the information obtained by the Committee, and they represented the best knowledge and the most efficient protection attainable at that time. In 1864, at the instance of Dr. Pole, a target was made representing a system of armour which he had seen applied to a French ship building at Cherbourg; it involved some novelties, and the trial was particularly instructive. The attention of the Committee, however, was not confined to ships only, but was largely devoted to the application of iron to permanent land fortifications. There were absolutely no facts on the subject of any value, and data could only be obtained by trials on a comprehensive scale. Accordingly, several structures were made on different plans that appeared feasible, and the result of the trials led to the development of satisfactory practical designs.

The Members of the Committee endeavoured throughout their work, not only to ascertain facts, but to reason upon them, and to make them useful for practical guidance. And when it is considered how little knowledge there was when they began their work, and that when they finished it they left the system of armour both for sea and land defences fully and successfully

Dr. Pole. established, it must be admitted that their four years' labours were not in vain. The great feature especially of the manufacture of the plates may be said to have been created under their auspices. In the twenty-five years that have elapsed since their labours ceased, no doubt great progress had been made, not only in the magnitude of the ships, but in the force of the artillery used against them, and the consequently larger scale of the armour; and it must, of course, be added that the new form of malleable material produced by fusion, whatever it may be called, had introduced great changes into the modes of preparation. It would be the province of others, who had the knowledge and the will, to give to the Institution information of these more modern improvements.

Frederick
mwell.

Sir FREDERICK BRAMWELL had nothing to remark on the engineering part of the subject, but he would like to refer to a question of political economy. Mr. Sydney Barnaby had proposed, in the interests of the ratepayers of the country, that the Government should make a certain class of ships, capable of receiving "woodite" protection, which, when not wanted for the purposes of war, should be leased out to the carrying trade as merchant steamers. If that could be done, he said such ships would be earning money instead of being a cost to the ratepayers in time of peace; also that, when war came and ships were wanted to bring food to the country, they would not be withdrawn from the merchant fleet in the way they otherwise would be. Sir Frederick Bramwell desired on this suggestion to remark that, for Mr. Barnaby's proposal to succeed pecuniarily, it would involve that, in times of peace, merchants should hire Government ships and should not build ships of their own; but as in time of war the Government ships must be withdrawn, and as by the suggestion the merchants would not have built ships, the vessels employed in the food trade would, when war came, be as much withdrawn as would be the ships owned by merchants, and there would still be the withdrawal of food-bringing ships. That would be one result, and the other would be that they would be allowing the Government to embark upon trading, which it was always too ready to do, competing with private capitalists, investing capital in the supply of ships and interfering with private commerce. He hoped that the Institution would always listen to anybody of the name of Barnaby, and certainly to Mr. Sydney Barnaby, with every respect in matters of engineering, but would be slow in adopting his views as to who ought to supply the merchant navy of the country.

'athaniel
by.

Sir NATHANIEL BARNABY thanked the members for the manner

Sir Nathaniel Barnaby.

in which they had received his Paper, with its many faults of omission, some of which had been happily corrected by Dr. Pole, and some faults of commission with which he should have himself to deal. With reference to the remarks of Admiral Sir George Elliot, he thought it was a great mistake to suppose that the rams of ships which had not armour carried out to the stem were therefore weak. The case had been quoted of the German ship the "König Wilhelm," which ran into and sank a sister ship, and it was said that the ram was seen to be twisted out of its place, and that was urged against the use of rams as at present constructed. The present form of ram had been very largely influenced by the failure of the German ram that had armour carried out to the end, which armour completely failed to support it. The method was changed, and he contended, having had a good deal of experience in the matter, that it was impossible to have a stronger form of ram than that now used in the British ships of war. If any one desired to convince him to the contrary, he should be happy to discuss the matter with him, but he believed it was impossible to have a stronger ram than that now in use, and he was certain that Mr. White would support that view. He regretted that he had not known of the great success which Messrs. Vickers had met with in their attempts to enter the field of armour-plate makers. That, however, was not his fault. The Admiralty had preserved its secrets well, and had resolved to keep undivulged all information as to who could make armour-plates, and, until the photographs were produced, he did not know how great a success Messrs. Vickers had achieved. He had singled out the firms of Messrs. Charles Cammell and Co., and Sir John Brown and Co. for special notice because they were the only ones in England who had made armour for modern ships of war, and he might be well excused for singling out those two great firms who had done such splendid service to the country. Captain Orde Browne had asked whether it was not possible to have hard armour for the cruisers to keep out the high explosives, and softer armour for the ships which were more heavily plated. To that a naval officer near him at once objected very naturally that it was uncertain what explosives the enemy might discharge. That objection to the use of different kinds of armour in cruisers and battle-ships was good also against the use of different principles in applying armour in cruisers and battle-ships, and was the justification for his treatment of the French ships in the diagram. His contention was that the principles of armour defence should be the same in all classes of fighting ships. Look at the Table of Phases of Armour. The ir Nathaniel arnaby.

"Gloire," a French ship of 5,500 tons, was designed to receive the attack of the fastest ships of that period, and to resist their shell guns. The "Tage," of 7,000 tons, was designed to do precisely the same thing. So, also, was the "Dupuy de Lôme." Why, then, should he not compare them in the matter of armour defence? Sir Edward Reed and Mr. White had stated that he must not do so, because they were called by different names. The "Gloire" was called a battle-ship; the "Marengo" and the "Amiral Baudin" were known as battle-ships; and the "Tage" and the "Dupuy de Lôme" were not. But in what respects would the enemy's guns treat them differently? In the last naval war the principle of defence was the same for all fighting ships. In the very largest ships there was the wing passage completely round the ship in the neighbourhood of the water-line inside; and the business of the carpenter and his crew in an action was to watch the whole of that wing passage and to have plugs with which to stop up the holes that the enemy's shot made. It was inconceivable to him that any arguments could convince an assembly of engineers, called upon to hear and judge, that there was any justification for protecting the crew of one fighting ship with 10 tons of armour per man, and leaving the crew of other fighting ships without any armour, vertical or horizontal. Sir Frederick Abel had drawn attention to conflicting statements in the Paper as to high explosives. Yes, they were certainly conflicting. One set had been put forward by official people who were defending the use of 4-inch and 5-inch armour in new ships as a perfect defence against high explosive shells. The other set supported his own view, that there could be no approximation to finality in the use of such armour. He had shown how the quick-firing gun and the automatic gun would be effective against it, and that the invention of armour-piercing projectiles loaded with those nitroglycerine compounds capable of piercing through even 12 and 14 inches of armour, must be expected. In a Paper prepared by him last year for the Naval Construction Company he had said, "4-inch armour for this purpose is already obsolete before the ships are finished." Sir Frederick Abel had confirmed that. He had stated that experiments had proved that 4-inch armour would not always keep out high explosives; that it would be penetrated by armour-piercing projectiles which would carry the explosive charge through the armour. He had said that, if the efficient application of high explosives depended only upon the provision of a thoroughly reliable delayed-action fuze, then the naval officer might depend on having, in the next war, high explosives brought,

Sir Nathaniel Barnaby.

with perfect efficiency, to bear against thick armour. In his Paper he had asked whether it was only the enemy who was to take advantage of those powerful projectiles. He had also deprecated the use of such armour. He had wondered whether it had been put into the recent large Admiralty designs in deference to a school represented by the gallant officer, Lord Charles Beresford. That officer had stated that the Admiralty had started first of all with the theory that an armoured battle-ship should not be sunk or put out of action unless its armour was pierced. He had himself always thought that where armour was used it should be endeavoured to make it impenetrable. It was said that such impenetrable armour was useless if the ship could be sunk or put out of action while it remained unpenetrated. But, according to the new school, there need only be put on some thin armour which would be speedily perforated, in order to set everything right. In order to put that armour on, the size of the ships must be increased at the expense of the number of ships; but no matter; the money expenditure per ship might be great, or the speed might be sacrificed, or thickness of armour or armament, in order to get some of that easily penetrable armour which would save the honour of the Navy, and justify the new school of naval architecture. It was said that the ship of 3,000 tons was very small. His object in advising those who prepared the design was to keep to a ship of minimum size for doing the work. That a ship could be made larger with advantage was, no doubt, true; but he thought the ship in question fairly balanced all the qualities that could be got in a ship of the smallest size capable of fighting an action at sea. The ship was practically as large as the "Asia" and the "Indus," the flag-ships of the Admiral Superintendents at Portsmouth and Devonport. He agreed with those naval officers who thought that any weather which would sensibly affect the comparative behaviour of the ship of 3,200 tons, and that of 14,000 tons, would be found to be not fighting weather for either ship. Mr. White preferred an armoured deck rising above the water-line in the middle, and sloping under the water to the sides, to the proposed raft body. He thought he was the first to introduce a deck under the water, with cellular divisions over it, in classes of ships which had hitherto been unprotected. That was in the C class of corvettes in 1878. He thought he was also the first to introduce the mode of defence preferred by Mr. White. That was in the "Mersey" class in 1883. If he should be the first to be instrumental in the use of the solid raft body in preference to either of those plans, he should think he had made a distinct and most important advance in the art of war-

Sir Nathaniel Barnaby.

ship building. In bringing his Paper before the Institution, he had had no desire to criticise any Admiralty work. He wished to direct attention to the new forces coming into the field, and to advise that outside engineering opinion should be taken before a large expenditure of money was finally decided upon. Since the Admiralty proposals had been made they had been considerably discussed. They were said to have met with the acceptance of the Navy. He had been listening that afternoon to an excellent lecture given by a naval officer, Captain Reade. The lecture was illustrated by beautiful drawings of ships, and it was a captivating lecture. The lecturer, however, had said some things about existing ships which he did not in the least agree with. He stated that the new Admiralty designs were quite wrong, and he contended that the ships should have armour all over their sides 6 inches thick. His view appeared to be that the design which the French had produced, of the "Dupuy de Lôme" type, was the one most needed for the largest ships. He had read with great interest a Paper in the "Nineteenth Century,"[1] for May, by Lord Armstrong, and he should be glad to quote a few words from it:—

> "It will be noted," said Lord Armstrong, "that Mr. White is careful to avoid all questions as to the policy of building armoured battle-ships in preference to ships of the cruiser class." He went on to say, "Although I am ready to commend the designs for these new ships, my distrust of the efficacy of all vessels of this armoured class in relation to their cost remains unchanged. All the advantage they possess in point of defence is a partial and imperfect protection against artillery fire. As regards rams and torpedoes, they are as vulnerable as ships without armour at all, and they are as liable to perish by the perils of the sea as any other kind of war-ship, while their cost is so great that the loss of any one of them from any cause amounts to a national calamity. Mr. White, in his Paper on these new designs, refers to what he calls the 'too many eggs in one basket' argument, but he wisely adds that he leaves that argument to be dealt with by the Board of Admiralty, who are responsible on matters of policy, he being only their technical adviser. The argument referred to is, however, undoubtedly possessed of great cogency, and, to my mind, the only justification for persevering in the building of such ships is that foreign nations are still doing so. Nevertheless, I maintain that we shall realise a greater amount of security for our shores, our harbours, our commerce, and our colonies, by chiefly devoting our resources to the multiplication of vessels of the cruiser class in preference to those of the armoured class."

Those were weighty words, and expressed almost what he had had in his mind in preparing the Paper. He would only add another word. England possessed two sets of very able sons—sailors and civil engineers. He had the highest possible admiration for sailors,

---

[1] Vol. xxv.—No. 147, pp. 629, 635.

Sir Nathaniel Barnaby.

whom he knew well, and who were very splendid men; but when it was decided to enter upon a national policy in such an important stage of affairs—such a crisis as the present—he thought that to shut out the great body of engineers, to whom questions of principle might be wisely referred, was a mistake. He thought every one would feel that, if it had been possible for the Admiralty to lay before a body of civil engineers the outlines which were put into Mr. White's hands (he was not now criticising the designs), it would have been much better than to enter upon a grave step in policy without such consideration as it ought to have received.

Correspondence.

Admiral Rt. Hon. Sir J. C. D. Hay.

Admiral the Right Hon. Sir J. C. DALRYMPLE HAY observed that when Sir Henry Chads reported, in 1850, that, "whether iron vessels are of a slight or substantial character, iron is not a material calculated for ships of war," he was justified by the character of the ship-plates of which some of Her Majesty's ships were being constructed. Substantial was a relative term, and the most substantial plate they applied to the sides of Her Majesty's ships did not exceed in any case ⅞-inch. These, under the fire of 32-pounder guns, with cast-iron spherical shot and 8 or 10 lbs. of powder, were driven in such masses of langrage that it would have been impossible for men to live behind them. It was not till 1854, after the failure of the Anglo-French fleet to effect, on the 17th of October, any material damage on the sea defences of Sebastopol, that, on the initiative of Napoleon III., wrought-iron plates were applied to the sides of wooden ships, to protect them against shell-fire. The first specimens tried in this country, at Portsmouth, towards the end of 1854, were made under the Tilt-hammer, and were 4½ inches thick. The spherical shells, at short range from 8-inch guns, broke up on striking, the plates received little or no damage, and the wooden structure was saved. He witnessed these experiments. The next opportunity of seeing an experiment was at Kinburn. The French had three floating batteries there, exposed at short range to smooth-bore guns. Some men were killed by shot which entered the large broadside ports; but though the battery, which he had an opportunity of visiting on that occasion, had been struck sixty-three times by solid shot, no plate had been penetrated or broken, and no bolt had been broken. In 1860 he was named Chairman of the Iron Plate Committee, and was associated with the late Sir William Fairbairn, Dr. Percy, General Sir

Admiral Rt. Hon. Sir J. C. D. Hay.

W. D. Jervois, and Dr. Pole. It might truly be said that nothing was known of the manufacture of iron plates for protection against shot when that committee assembled; when it was dissolved, in 1864, it left a record of experiments and opinions which even now, in the advanced stage of the science, might safely be consulted. The "Warrior," "Black Prince," and "Achilles" were in process of construction, but the "Minotaur," "Agincourt," and "Northumberland" were constructed in consequence of the advice of the Iron Plate Committee, and the rolls by which the plates were constructed were put up by Sir J. Brown in consequence of evidence taken by the Iron Plate Committee of the superiority of plates so constructed to those made under the Tilt-hammer. The turret of Captain Coles led to the "raséeing" of the "Royal Sovereign," and afterwards to the experimental fire to which she was subjected from the guns of the "Bellerophon." During the decade 1860 to 1870, several incidents occurred to make naval men sceptical as to low freeboard, breech-loading guns of large calibre, and the reliance upon a small number of large guns in preference to the broadside. Vessels of the "Agincourt" class had proved exceptionally fine sea-boats. They had assisted in laying an Atlantic cable; they had towed a dock successfully to Bermuda. The "Royal Sovereign" had been damaged in a contest with the "Bellerophon," and the "Captain," through being over-canvassed, had perished. One of the most formidable turret-ships ever built was thus lost, owing to the wish of the designer to make it also a sailing ship, against the advice of Sir Edward Reed, then Chief Constructor. The 40-pounder Armstrong breech-loader, with 8 lb. charges, was ineffective against the $4\frac{1}{2}$-inch plates, and a 150-pounder breech-loader gun jammed in the breech, and was unable to be reloaded, in experiments at Shoeburyness. Thus it came to pass that want of confidence in a breech-loading gun capable of standing heavy charges, and the reliance upon many guns rather than on few, induced many officers of ability, such as the late Sir Cooper Key, to rely upon muzzle-loading ordnance and broadside ships. The resistance to an increase in the size of ships was intelligible. There was no need to build ships much larger than possible opponents. Since the making of the Suez Canal, the Indian empire was deprived of the support of the Mediterranean fleet, if its ships drew more than 24 feet 8 inches. There was no advantage in increasing the risk on each individual ship, or increasing the cost, unless concentration of power was advisable for other reasons. The Author had quoted accurately some remarks of his, giving a general assent to Admiral Touchard's expressed opinion. He saw no reason to change the opinions then expressed.

Admiral Rt. Hon. Sir J. C. D. Hay.

In specifying in their order the parts requiring protection, he saw no necessity to alter the respective values of the arrangement quoted. But, in the speech quoted, he previously stated that seaworthiness and speed were above all things necessary. He still adhered to that statement. It must be remembered that in 1873 the torpedo was hardly developed, and the "Polyphemus" had not been tried. The torpedo might be guarded against by crinoline, but the ram could only be used or avoided by speed and handiness. This brought him to the special proposal of the Paper. If the raft-bottom proposed could be made so as to receive the damage inflicted by the torpedo, in such a manner as to lessen the risk of sinking, it would have most valuable results; but this material was, so far as he was aware, not yet even in the experimental stage, and he should be impertinent to offer any opinion on its merits. Small ships of this character would be invaluable, and have many of the advantages claimed by the Author; but they did not, in his opinion, do away with the necessity for building large first-class battle-ships. They probably were an improvement on the "Riachuelo," though four of them did not seem to be a substitute for the "Victoria." How rapidly the march of science caused opinions to develop, and how difficult it must be for an outsider like himself to express a confident opinion, was illustrated by the fact that Sir Edward Reed and the Author, two of the most eminent naval architects in the world, and who had each worn the blue riband of their profession as Chief Constructors of the British Navy, were not absolutely in accord on this subject, and neither of them, when in office even, so far as was known, submitted such a design to the public or the authorities. This country had been at war at the same time with France, Holland, Italy, Turkey, Russia, Denmark, Sweden, and the United States. The British Navy then consisted of one hundred and forty-six line-of-battle ships in Commission, and in 1807 Great Britain seized the Danish fleet at Copenhagen, and in 1808 the Russian squadron in the Tagus, in order that it might have as many battle-ships as all the world besides. This policy was carried out by Chatham and Lord Anson, by Mr. Pitt, Lord Howe, and Lord Barham, and was the only policy which gave this country absolute safety. This superiority was needed not at the end but at the outbreak of hostilities; wars were short, sharp, and decisive, and those best prepared, like Germany on a recent occasion, were successful. Other classes of ships might be extemporized, but a first-class battle-ship took four years to complete. It was better to spend money in building such ships, in case they might be wanted, rather than in paying a ransom after defeat. There

Admiral Rt. Hon. Sir J. C. D. Hay.

were now one hundred and four first-class battle-ships in the world. Great Britain had thirty-four. It was proposed to build ten new ones. To that must be added twenty-six with a speed and gun-power superior to the "Italia," with a protection over the vital parts superior to the "Italia's" guns. As the offensive power of the "Italia" could be developed by direct fire in a line with keel of all its four guns, and as the bow, in ramming, was most exposed, so it seemed to him it was essentially needful that a narrow belt of protection at the water-line should be given, as the punching fire of quick-firing guns might possibly materially injure that portion of the ship. Before closing, he desired to emphasize an opinion he had always ventured to express since the abolition of the Ordnance Office in 1855. The Ordnance Office was essentially a manufacturing department, though it was overlaid with detail of the Corps of Royal Engineers and Artillery. Those corps were justly attached to the War Office, but the construction of guns and the provision of munitions of war should be entrusted to a department separate from the two great spending departments. The nation might then hope to have guns ready in good time for its ships, and identity in make and calibre in the armament of its ships and fortresses. Until this was done, he feared the difficulty in providing a suitable armament for ships would continue, and he could conceive nothing more fatal to the naval supremacy of this country than that a ship or a fleet, resorting to Gibraltar or Malta, should find guns and ammunition of a different character to that which they might require. England must be guided by the course of shipbuilding in nations which might be possible opponents, and for every battle-ship laid down by foreign countries, a faster and more powerful ship should be commenced and rapidly completed here.

ajor Callaghan.

Major D. O'CALLAGHAN, R.A., remarked that a tolerably long experience of armour-plate experiments at Shoeburyness led him to hail with satisfaction the proposal to abandon the type of unarmoured fast-steaming cruiser, in favour of a vessel which, while possessing the undoubted advantages of high speed and manœuvring power, would afford a measure of protection to guns and gun's crews from the disastrous effect of an enemy's shell fire. With respect to ships which depended for their existence on speed alone, Englishmen were not fond of rapid strategic movements to the rear. Such evolutions were at times open to misconstruction, and captains whose orders were to hover on the outskirts of an engagement, and whose *rôle* was to convoy merchantmen or to bombard mercantile ports, would inevitably turn their blind eyes

Major O'Callaghan.

towards signals, and would try conclusions with ironclads in the thick of a fight with the certain fate of destruction. The "plucky little 'Condor'" incident would be repeated over and over again with less happy results. He well remembered the terrible effect of common and shrapnel-shell fired some years ago at a section of the "Shannon" at Shoeburyness; and he made up his mind then that it was almost useless to protect the so-called vulnerable portions of such a ship, the engines, steering-gear and magazines, when the fighting portions, the guns and their crews, were open to complete and total destruction by the feeblest projectiles. A delayed-action fuze for high explosives was not, as the Author remarked, an accomplished fact, and shells filled with high explosives were powerless when fired against armour, unless the latter was very much below the perforating power of the gun opposed to it. There was little doubt, for instance, that 4 to 6 inches of hard armour, easily perforable by a 6-inch breech-loading gun, would be quite proof against a shell of that calibre filled with high explosive which would detonate on impact, causing the shell to break as harmlessly as an egg on the face of the armour. On the other hand, a similar shell from a 9·2-inch or 10-inch breech-loading gun would probably overcome such a thin plate, detonate in passing through it, and though, as far as disruptive power was concerned, its explosion would probably be more local and less damaging to structure than that of a powder-filled shell, the number of man-killing fragments would be greater, and the execution in this respect proportionately to be dreaded. This effect, too, would, he took it, be quite independent of any fuze delayed or direct in its action, but would be dependent solely on the disparity between the armour protection and the power of the gun. Steel-faced armour, 9 inches thick, such as the Author proposed to use in the new type cruiser, was just perforable by a 6-inch armour-piercing steel shell at short range; but it would, he thought, keep out a shell filled with high explosive fired from a 9·2-inch breech-loading gun striking normally to its surface, and would afford an efficient protection from even heavier shells striking at an angle. The effect of these projectiles, owing to the disruptive force being confined to a comparatively restricted area, might be discounted and localised to a great extent by the employment of traverses, and this, he would suggest, should be an important factor in future construction. On the general question of building four comparatively small ships instead of one large one, it would be presumptuous for him to express an opinion; but the policy must surely be sound, since the four ships were practically as invulnerllagham.

able as the one bulky ironclad, were more easy to manœuvre, and were susceptible of both independent and combined action. All the eggs were not in one basket, and the loss of one of the baskets would not necessarily involve the destruction of the other three.

-Admiral

Rear-Admiral R. A. E. SCOTT observed that the Author's proposal was to build five small partially-armoured ships of 3,200 tons each in lieu of every intended battle-ship of 14,150 tons; or else four ships of rather larger size and higher speed. The former were to steam 17 knots, and the latter 19 knots an hour, as against the 17½ knots of the new battle-ships. The vessels proposed by the Author were to be armed with two 22-ton guns each, and armoured so as to protect the crews of these guns, which were to be mounted one on each side of the funnel, and to sweep round the horizon. The lower part of the funnel, together with the uptakes from the boilers, and the vital parts of these ships were to be protected. The quadrupling of partially armoured vessels, having their two guns, their crews and funnels protected, and capable of steaming 19 knots an hour, would be of great advantage, could sufficient coal-endurance be given them; but unfortunately they could not, upon such small tonnage, carry coal enough to keep at sea for the lengthened periods requisite to defend the more distant commercial arteries, and were not, therefore, the ships which were so greatly needed for the protection of commerce. The utilizing 9-inch armour, so as to afford such a considerable amount of protection, appeared to entail the disadvantage of over-heating the gun-chambers by radiation from the funnel; but, on the other hand, the Author's calculations as to perforation by the 9·2-inch 22-ton guns of no less than 99 per cent. of the area of the sides of foreign ironclads, was a most valuable contribution at the present time. He further stated that the 69-ton guns carried by the present battle-ships would only pierce ½ per cent. more of this area, which must at once suggest the query whether the 69-ton guns were valuable in proportion to their weight of metal and of armour needed to protect them and their easily injured machinery. The Author had pointed out Sir Thomas Hastings' mistake in condemning iron as the material for the skin of warships; but the same conclusion had been arrived at by all who witnessed the large pieces of iron which were torn off when the target was struck by projectiles. Latterly, great improvement had been made in the toughness both of iron and steel, but there was very little experience as to the damage likely to result from shell-fire against the unarmoured sides of vessels. Shots were unsuitable as naval missiles. Properly made steel shells would perforate any thickness that shots would penetrate, and then explode within the ship, as had been long since proved by Sir Joseph Whitworth. For steel shells there was a safer and quite as powerful a material as any which had yet been manufactured abroad, and the mechanical ability to apply every kind of explosive in the best manner was likewise to be found in the United Kingdom. He believed that the proposed large battle-ships of 14,150 tons, or a few hundred tons more for larger coal-supply, were the very ships now most needed for the Navy, and the least likely to become obsolete. The Author had directed attention to the imperfect gun-supply, and had shown the practical value of guns of 22 tons weight; but trustworthy 10-inch guns of about 30 tons would be still more suitable for ships, as their diameter would admit of the more powerfully explosive shells which would more quickly complete the destruction of the sides of an enemy's vessels. **Rear-Admiral Scott.**

16 April, 1889.

SIR GEORGE B. BRUCE, President,
in the Chair.

The discussion on the Paper by Sir Nathaniel Barnaby, on "Armour for Ships," occupied the entire evening.

23 April, 1889.

This being the Tuesday in Easter week, in accordance with the By-laws there was no meeting.

30 April, 1889.

SIR GEORGE B. BRUCE, President,
in the Chair.

The discussion on the Paper by Sir Nathaniel Barnaby, on 'Armour for Ships," was continued and concluded.

SECT. I.—MINUTES OF PROCEEDINGS.

7 May, 1889.

SIR GEORGE B. BRUCE, President,
in the Chair.

The following Associate Members have been transferred to the class of

Members.

DAVID BALFOUR.
PHILIP BULMER.
THOMAS PROCTER CAMPBELL.
ALFRED COLSON.
CHARLES GOOD.
WILLIAM STRONACH LOCKHART.
WILLIAM MATTHEWS.
CHARLES LANGBRIDGE MORGAN.
EDMUND ALFRED PONTIFEX.

The following Candidates have been admitted as—

Students.

JACINTO ANZORENA.
FREDERIK OLE ERICHSEN.
RICHARD GOODMAN.
FREDERICK WALTER HODSON.
ERNEST PERCY MCKIE.
GEORGE WILLIAM JOHN EARNEST MANNING.
ARTHUR BANKS RIGBY.
WILLIAM SIMPSON.
ARCHIBALD CHARLES DOUGLAS STEELE.
THOMAS GEORGE TAYLOR.
BERTRAM THOMAS.

The following Candidates were balloted for and duly elected as

Members.

ROBERT BARKER.
GEORGE BOND.
JOHN AUGUSTUS ARNOLD BUCHHOLZ.
WALTER KATTE.
WILLIAM SHIELD.
WILLIAM WILKINSON SQUIRE.
GEORGE HUNTINGTON THOMSON.
WILLIAM STEELE TOMKINS.

Associate Members.

JAMES ANDERSON.
ERNEST CRAIG.
ALFRED DICKINSON.
ERNEST RICHARD DOLBY.
FREDERIC JAMES EDGE, Stud. Inst. C.E.
GERALD FITZGERALD.
WILLIAM JOHN HANCOCK.
CHARLES GEORGE HENZELL.
ALEXANDER HILL.
FREDERICK THOMAS HOPKINSON.
WILLIAM GEORGE WOOLLCOMBE LAKE, Stud. Inst. C.E.
CHARLES DE LA POIRE CRAWFORD LINDESAY.
JENNER GUEST MARSHALL.
JOHN HENRY PARKIN.
EDWARD MARTIN SMITH.
WILLIAM JAMES TAYLOR, Stud. Inst. C.E.
WILLIAM THOMAS.
GEORGE BLAKE WALKER.
EDWARD THOMPSON WARD, Stud. Inst. C.E.
ERNEST WILLIAMS.
HENRY MORTON WILLIAMS.
WALTER WILLIS, A.K.C.

(*Paper No. 2402.*)

"The Treatment of Steel by Hydraulic Pressure, and the Plant employed for the purpose."

By William Henry Greenwood, M. Inst. C.E.

The Author's original intention was to have combined within a single communication a consideration of the operations themselves, and of the plant required for the treatment of steel by hydraulic pressure, involving thus the processes or operations generally known as, 1st, the fluid compression of steel, and 2nd, the hydraulic forging of steel. It was found, however, that the length of such a Paper would far exceed the usual limits, while the considerations involved in the study of the two processes are in a great measure different. It was considered, therefore, better to take the subject in its two divisions separately, hence only the first mentioned will now be presented for discussion, namely the fluid compression of steel for the production of sound ingots, upon the method suggested originally by Sir Henry Bessemer in 1856, but the practical carrying out of which is inseparably associated with the name of the late Sir Joseph Whitworth, Bart. Attention will thus be directed to blow-holes in steel, to their origin, and to the various methods proposed for the production of sound ingots; but more especially to the method, effect, and advantages of fluid compression. The development of this, and of the hydraulic plant necessary for that purpose, culminated in the construction, erection and working under the Author's supervision in the Abouchoff Works, St. Petersburg, of a complete plant, embracing engines, pumps, accumulators, lifts, cranes, moulds, and a press of 10,000 tons capacity. This was then the most powerful plant that had been constructed for the purpose, and it affords, further, probably the only example in Russia of a plant of anything like equal magnitude and novelty, for which the whole of the labour required in the preparation of the drawings, of its construction, erection, and subsequent successful working was supplied (with the exception of the Author) from the ordinary staff of the Russian works. The descriptions and data throughout this Paper refer largely to that plant and its working, supplemented only where necessary by information from other sources. It is remarkable that although several steel-makers, notably The Barrow Steel Company, Limited; Schneider, of Creusot, and Baron

Krupp, of Essen, did from time to time make overtures, and open up negotiations with the late Sir Joseph Whitworth, for the construction of the necessary plant and use of the process, yet failure always attended such overtures, and while Sir Joseph Whitworth and Co. remain the only users on the large scale of the process in this country, the Abouchoff Works represents its continental home. The Author is able to place before the Institution a large experience of the working of the process, and by the courtesy of Admiral Kolokoltzoff, I.R.N., Director of the Abouchoff Steel and Ordnance Works, St. Petersburg, to present an important series of tests and experiments made upon steel cast under the ordinary conditions without pressure, and upon similar steel cast and then subjected whilst fluid to considerable hydraulic pressure.

Sir Joseph Whitworth claimed for the method of fluid compression, that it was the only process yet introduced by which ingots of mild steel could be at once successfully obtained sound, free from cracks or other flaws, homogeneous, and for the same temper of steel with the higher ductility, so desirable in the manufacture of ordnance, shafts, or any large forging. How far these anticipations have been realized is another of the objects which this Paper is intended to show; and lastly, it is hoped that the communication may partially fill a void which has hitherto existed in the published information, and hence supply general knowledge upon an important process, and upon a series of improvements in plant employed for the manufacture of the very highest qualities of mild steel.

UNSOUNDNESS OF STEEL INGOTS.

Before proceeding to a description of the plant, the conduct of the operation, and the effect of fluid compression upon steel, a few words upon the necessity for some such operation may not be out of place. But in treating this preliminary matter, the Author will endeavour to avoid the introduction of matter calculated to raise any discussion of a strictly chemical character. Further, the remarks now offered are confined more particularly to those classes of steel whose quality, temper, and composition fit them for use in the construction of ordnance, large crank and propeller shafts, or other heavy forgings, as also of cylinder liners, axles, torpedoes, and war material generally, but do not necessarily, or in their full force, always apply to the qualities and requirements of steel as used for rails, tires, or the general run of rolling-mill products.

It is usually accepted that molten steels, especially such mild steels as contain not more than 0·5 per cent. of carbon, when received in the ladle or mould from either the Bessemer converter, the Siemens furnace, or from the crucible, possess the power of occluding or holding in solution a considerable volume of such gases as hydrogen, nitrogen, carbonic oxide, and carbonic anhydride, derived from the products of combustion in the furnace; whilst possibly a further portion of gas is carried mechanically into the mould by the stream of metal as it runs from the ladle. Of this latter, doubtless, in a well-cast ingot much of it would again escape from the metal.

The occluded gases are supposed to be eliminated only at the moment when the metal changes from the liquid to the solid condition, as occurs in the oft-quoted and well-authenticated examples of hydrogen from platinum, of carbonic oxide from palladium, and of oxygen from silver under like conditions; but in the case of steel, the gases so liberated being unable readily to escape from the solidifying mass, attach themselves to the particles of steel, and are imprisoned possibly in a high state of tension, and occur in the form of bubbles throughout the mass as the metal solidifies, the surface of the bubble-shaped cavities being generally almost silver-white in colour. The extent to which such blow-holes, as they are called, occur in steel ingots, appears to vary in some inverse ratio to the rapidity with which the ingot cools; the longer the interval between the commencement of solidification and its completion, the more complete and larger is the separation of the gases, as judged by the unsoundness of the ingot afterwards. It is also suggested that in the Bessemer and Siemens processes, beyond the elimination of occluded gases, there may probably be a continuation, after the metal has run into the mould, of the reaction between oxides of iron dissolved or otherwise present in the metal as tapped from the furnace, and the carburized manganiferous compounds, spiegeleisen, ferro-manganese, &c., added in the last stage of the manufacture, whereby a small evolution of gases may occur after the metal has partially solidified; but if this be so, it follows that such gases can only be either very small in amount, or are again finally occluded by the metal and do not evidence themselves after complete solidification, since the gases occupying the blow-holes in steel consist of some 78·5 per cent. of hydrogen with 20·5 per cent. of nitrogen, and only 0·2 per cent. of carbonic anhydride with 0·8 per cent. of carbonic oxide, as first shown by Professor Müller.[1] Hence, if the two last mentioned gases are present in the molten steel to any considerable extent, it follows either that they always escape, or otherwise remain largely occluded in the metal after solidification; while the hydrogen and nitrogen are either not occluded by the solid metal, or are so in a lesser degree than by the fluid steel, and hence their predominance in the blow-holes of steel ingots.

---

[1] Minutes of Proceedings Inst. C.E., vol. lvi. p. 360, and vol. lx. p. 495; or Berichte der deutschen chemischen Gesellschaft, No. 1, 1879.

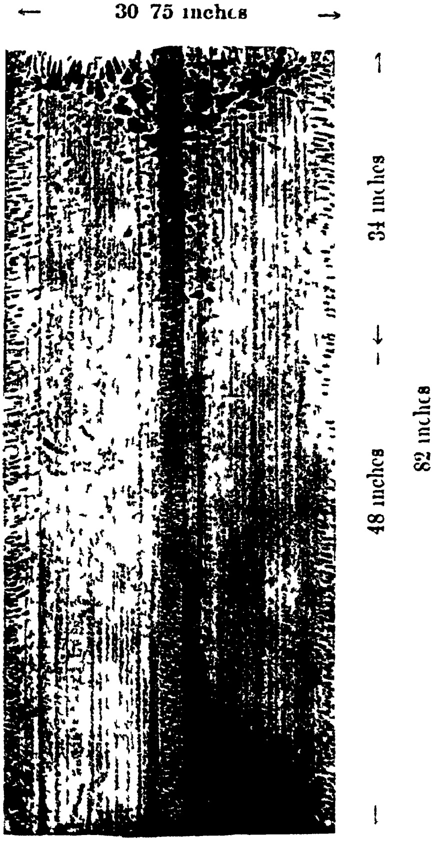
Beyond the blow-holes formed as just described, there are probably other sources of unsoundness, like the porosity or sponginess and piping that occur towards the axis and head of the ingot, and which are probably due to the outer skin of the ingot first solidifying and contracting, whilst the interior still remains fluid. But as the interior subsequently solidifies and cools, it would contract towards the outer walls of the ingot, and thus leave other (contraction) cavities towards the central axis of the same.

It is further noticeable that the milder and more ductile the metal, or the greater its freedom from elements other than its fundamental constituents, iron and carbon, so is this tendency to general unsoundness increased. So also each increase in the diameter of the ingot, whereby solidification of the fluid metal is delayed, increases the difficulties of producing comparatively sound ingots, since all external cooling influences, both natural (as from the metal of the mould), or artificial (as by the application of water-jackets or the use of variously formed moulds), are correspondingly less effective in promoting the desired object.

The extent of the unsoundness in mild steel ingots, by which is here meant the volume of the blow-holes, honey-comb and piping, which would be presented in an ingot cast under the identical conditions which prevail where hydraulic pressure is applied to the fluid metal, but without the application of such pressure, amounts, as determined by the difference in volume of the ingots as pressed and unpressed, to from 8 per cent. to 12 per cent. of the total volume of the ingot when cold, and so rendering corrections for contraction practically unnecessary.

Whether the theories just enunciated be true or not, the unsoundness which occurs in steel ingots, as shown by Fig. 1, and by the samples of small and large ingots exhibited, which represent ingots equal to, if not above, the average production, is the subject of very considerable trouble and loss to the steel manufacturer. The form which the unsoundness presents varies considerably; it may form a single longitudinal pipe surrounded by bubbles, or at other times the bubbles may be concentrated into a pear-shaped chamber of considerable dimensions, surrounded by unsound metal with other smaller cavities, or bubbles irregularly distributed around and below the apex of the cone; or again, the bubbles or blow-holes may be of varying size, and irregularly distributed throughout the whole mass of the ingot. But they are usually largely concentrated towards the upper end or head of the ingot, so that large ingots of mild steel of either Bessemer, open-hearth or crucible manufacture, and of a quality suited for ordnance purposes, when cast in the ordinary open-topped moulds without pressure, present such a concentration of irregularly distributed blow-holes in the upper part of the ingot that it is always necessary to reject from 30 per cent. to 35 per cent, and not unfrequently 50 per cent., of the metal from the top end, and this amount represents therefore so much waste in the ingot. But besides this loss in head, the

FIG. 1



unpressed ingot usually, as shown in Fig. 1, presents a surface porosity and acicular structure, the cells of which, unlike the silver-white bubble-shaped cavities already spoken of, often have an oxidized or iridescent appearance. This weak structure and unsoundness will sometimes extend over the surface for the whole length, as also over the bottom, of the ingot, penetrating to a depth varying from 1 inch to 3 inches from the surface, according to the size of ingot, the conditions of casting, as to temperature, &c., to the nature of the mould and its coating, and also to the quality of the steel. This kind of unsoundness and defective structure renders the surface of such ingots weak under tensile-stresses, while forgings from the same are roaky, seamy and unclean from the hammering out and imperfect closure of the surface honeycomb; hence amounts, varying from 10 to 20 per cent., have to be allowed in the weight of such forgings for turning and general machining, before clean forgings of the requisite strength can be ensured. The unsoundness extends towards the centre, in the 30·75-inch ingot represented in Fig. 1, to about 3 inches from the surface, both at the sides and over the bottom of the ingot.

Fig. 1 represents the condition of the average unpressed ingot, but with other tempers of steel, and less favourable conditions of the metal when cast, very frequently larger, and occasionally smaller, losses may occur from unsoundness; thus with badly melted or badly cast crucible metal, the whole ingot may become so unsound as to necessitate its entire rejection. In rails of Bessemer steel, rolled from ingots 14 inches square in cross section, where the rolling effaces sufficiently for rail purposes the evidences of a considerable proportion of the unsoundness, the croppings which arise from original unsoundness still amount to some 8 per cent. of the original ingot. In the manufacture of steel castings, all are familiar with the large amount of scrap produced in the form of casting heads, risers, and so on, where solidity of casting and mild temper of steel are required. Mr. Seebohm, in a lecture delivered in 1881, before the Cutlers Company, gave his experience in trying to make gun-barrels of Bessemer steel. He said: "If the steel was soft enough to stand the test, I had to break up 40 per cent. to 50 per cent. of the barrels for scrap, because they were unsound. If the barrels were sound they were so hard that they would not stand the test." Sir Joseph Whitworth has said, in "Guns and Steel,"[1] that he was induced to take up the manufacture of steel, and thus of the process for submitting ductile steel when in its molten state to extreme pressure, by the difficulty he experienced in obtaining sound and ductile steel for the material of rifled guns; and a short perusal of the Patent Office specifications is sufficient to show that the unsoundness of mild steel ingots, especially of large size, is now and must have been a generally accepted fact from an early period. For names like those of Bessemer, Siemens, Whitworth, Krupp and numerous other manufacturers frequently appear with arrangements for applying pressure in some form or another to the fluid metal, in order to overcome the difficulty.

---

[1] Miscellaneous Papers on Mechanical Subjects. Guns and Steel, by Sir Joseph Whitworth, Bart., London, 1873.

Blow-holes in steel ingots are not eradicated, nor perhaps is their volume seriously diminished, by the work of forging the metal, except at the surface, where during working the holes more or less break out, producing the surface defects already referred to, while the cavities in the interior of the ingot are probably only drawn out. This has been shown by Mr. D. Chernoff[1] in Fig. 2, which represents to half size a radial section cut across a gun forging from the bore towards the jacket, where local cavities are distinctly seen; but they are all elongated by the forging in the direction of the axis of the ingot, and are more strongly marked towards the bore or centre of the ingot, the ingot being of ordinary unpressed gun material.

Fig. 2.

METHODS EMPLOYED FOR IMPROVING THE SOUNDNESS OF MILD STEEL INGOTS.

To save the invariable loss from the unsoundness due to gas bubbles and contraction cavities, and therefore also the want of homogeneity and reliability of mild steel ingots as cast in the ordinary fashion, together with the hope, at the same time, of improving the quality, increasing the strength and the ductility of the metal, have long exercised the minds of steel-makers, and increasingly so with the demand for larger masses of mild steel for constructive purposes. The Author is not unmindful that much can be done to promote the solidity of steel ingots, especially of small size, by careful attention to the melting (dead-melting), observance of the temperature at which the metal is run, the method of running, the preparation of the moulds, the ratio of length to diameter of ingot, and even by a judicious selection of the mixtures of materials for the furnace or crucible charge. But after all precautions, Fig. 1 still represents the average condition of the product where large ingots of mild steel are the desideratum.

---

[1] Chernoff, "On the Structure of Cast-Steel Ingots." Read before the Imperial Russian Technical Society, 2nd December, 1878, and translated by Mr. W. Anderson, M. Inst. C.E. [Inst. C.E. Tracts, 8vo, vol. 324.]

Of the various proposed methods of procedure, having for their special object the production of ingots free from blow-holes, &c., it will not here be necessary to refer to more than two classes: viz., the chemical and the mechanical, or occasionally combinations of the two.

Of the methods depending (for whatever measure of success has attended their application) upon an increase in the proportion of, or introduction of, foreign matters into steel, the most notable are those in which silicon, manganese and aluminium are employed. It is an accepted fact that the introduction of manganese tends to promote freedom from blow-holes, but it has also the effect of hardening, lowering the ductility and general reliability of the metal, so much so that few engineers are to be found who will acquiesce in the introduction of more than a small quantity (quite insufficient to ensure sound ingots) of manganese into steel for any of the applications to which the Author has referred. The effect of an increased content of manganese appears to induce a tendency for the bubbles to concentrate themselves towards the axis of the ingot rather than towards its surface.

The Author's experience of the effect of silicon upon mild steel is that it distinctly hardens or increases the tensile-strength and raises the elastic limit of the metal; but it reduces the ductility and the amount of contraction in area before fracture occurs. The fracture is also more uneven, and marked by transverse ridges; while the unsoundness tends to concentrate itself along the outer surfaces of the casting. The use of silicon has been exceedingly beneficial in some departments of the steel industry, especially in the casting departments, and it is, therefore, more advocated than manganese or other alloys; but, accepting silicon as perhaps a necessary evil in the production of steel castings, the Author is disposed to admit the position that the less silicon in the steel for a gun, a shaft, projectile or an armour-plate, the safer is the user of the material against unexpected disaster from his own weapons;

and, notwithstanding the advocacy of certain foreign engineers and metallurgists, it is difficult to conceive that a siliceous steel, even though sound and of a mild temper, will ever be extensively adopted for the purposes before mentioned, so long as a sound and practically homogeneous material is obtainable without the use of silicon.

It has been suggested that the addition of a material which lowered the melting-point and increased the fluidity of molten steel would promote the elimination of gases and the freedom of the ingot from blow-holes. With this object aluminium has been introduced into the metal, and experiments are still being pursued upon this subject both in this country and upon the continent, but as yet the experience and data available are insufficient to decide the question.

Of the mechanical methods, or such as aim at the production of solid ingots of steel without altering the chemical composition of the metal, it will here only be possible to name a few of the more prominent types, and without always identifying them by specific names. To this class of proposals belong the methods in which external cooling is promoted by the application of steam or water upon the outsides of the moulds, or by water-jacketing the same; or else by alterations in the form and relative thicknesses of the sides of the moulds; then there are various proposals for agitating the metal during solidification, as by simply tapping the sides of the moulds with hammers; agitation after the manner proposed by Mr. Chernoff and others. For special forms a whirling motion, such as that suggested by Mr. F. W. Webb, has been tried, and even subjecting fluid steel to a vacuum has not been without advocates; whilst proposals for the production of complete solidity, homogeneity, and by inference therefore of greater uniformity and reliability, more ductility and a slightly increased tensile-strength of metal for any definite chemical composition, by the direct application of pressure applied in various forms to the surface of the fluid metal in the mould, have been made and tried by numerous inventors both before and since Sir Joseph Whitworth's success. With the practical conduct of some of these experimental trials the Author has been associated; but, with the exception of fluid compression, in which hydraulic pressure is used, all have, the Author believes, signally failed from practical difficulties attending their application and the totally inadequate pressures employed. Thus Mr. Jones[1] proposed, and tried at various works in America and in this country, a method for the compression of fluid steel by the direct application of steam, at a pressure of from 80 lbs. to 250 lbs. per square inch, to the upper surface of the fluid metal in a suitable mould. Almost simultaneously a similar device was tried in France; another analogous proposal from America is to inject water through the cover of the ingot mould on to the heated metal, the steam so generated being supposed to act as before, only with greater efficiency. It has been proposed to introduce beneath the cover of a closed top mould, and upon the top of the metal, explosives, like mixtures of charcoal and nitre or of other chemicals, which, under the influence of heat, decompose and produce the desired gaseous pressure. Solid carbonic anhydride has also been tried with the same object, but all such attempts to obtain solid ingots have proved abortive; and they serve only to show that neither the intensity of the pressure required, nor the interval for which it must be continuously applied, in order to produce sound ingots of even moderate dimensions, had been appreciated. The mechanical difficulty of constructing moulds and connections which, whilst containing fluid steel, should remain gas-tight, and the difficulty of providing a gaseous body which would remain gaseous at any approach to the pressures necessary for ensuring soundness of the ingot, would appear to warrant the conclusion that failure was inevitable in all such cases. It appears certain from these experiments, however, that any process which causes pressure to be exerted over the surface of the fluid metal, will, according to the promptness with which it acts, and the intensity of the pressures attained, produce ingots less honey-combed than where such pressure has not been applied; but for the production of ingots practically sound and free from blow-holes and contraction cavities, hydraulic pressure alone appears to have been effective. In a recent experiment,[1] it was shown that whereas a pressure of 12,000 lbs. per square inch on an ingot 3·5 inches square did not produce solidity, yet a 20,000-lb. pressure ensured a perfectly sound ingot. Experience with the hydraulic press shows, however, that an improved product, free from weak acicular structure and of almost perfect solidity, can be obtained with a pressure of from 2 to 6 tons per square inch upon the surface of the fluid metal, according to the size of the ingot and other conditions; but for absolute solidity, in some cases even 15 or 20 tons pressure per square inch on the surface of the fluid metal is necessary.

---

[1] Of the Edgar Thompson Steel Works, U.S.

Engineering and Mining Journal, vol. xlvi.

The method now known as "Fluid Compression" was proposed by Mr., now Sir Henry, Bessemer, in 1856; but it is to Sir J. Whitworth and Co. that the development of the plant and the demonstration that the method could be carried to a successful practical and commercial issue, are largely due. It was only in 1866 (the date of Sir Joseph Whitworth's first patent on the subject), or even subsequent to this, that fluid compressed steel became obtainable as a regular and marketable commodity. The process is hence now generally known as Whitworth's method for the fluid compression of steel, and, despite its many advantages for heavy high-class work, yet the actual working of the process upon the large scale is still confined to the works at Manchester and to the Abouchoff works in St. Petersburg, at both of which it is in daily operation to the entire satisfaction of those directly concerned. It is upon personal experience of the practice, and of experiments conducted principally, although not entirely, at Manchester and St. Petersburg, that the conclusions arrived at in this Paper have been deduced. The subsequent description of plant for the fluid compression of steel, and of the exhaustive tests which are herewith included, Appendixes I, II, III, IV, V, VI, VII, VIII, have reference principally to the conduct of the operation and product produced at the Abouchoff Works, and which the Author is permitted to publish by the courtesy of Admiral Kolokoltzoff, I.R.N.

THE HYDRAULIC PRESS, MOULDS, AND PLANT FOR THE FLUID COMPRESSION OF STEEL BY HYDRAULIC PRESSURE.

The ordinary open-topped moulds in which ingots of large size are cast, when not subjected to special external pressure, consist usually of a cast-iron casing, with a small taper from the top to the bottom, so as to allow of its ready subsequent stripping from the cast ingot. This casing stands, as shown at M in Plate 1, Figs. 1 and 2, upon a massive cast-iron bottom or base, upon which the molten metal falls during the first stage of the casting operation. Such moulds, after coating with a wash of blacklead or of lime, are carefully dried and warmed, and are then ready for receiving the molten metal. At other times such cast-iron moulds are replaced by wrought-iron casings, lined either with a thin layer of composition or of bricks, or first with bricks and then with composition over the inner surface. The coated mould is warmed as before, and is then ready for the reception of the metal.

Obviously such moulds as these would be inadequate if the metal were to be subjected while fluid to pressures amounting in the aggregate to thousands of tons. Accordingly, moulds constructed after the manner shown below, in Figs. 3 and 4, were designed. The mould is that in which the 34·25-inch ingot, to be subsequently referred to, was cast. It consists of an inner forged steel casing, about 4 inches in thickness, which is usually rough turned and bored, with a slight taper from top to bottom. This cylinder supported externally by a series of other steel hoops, dropped on after the manner adopted in gun construction; and a trunnion ring is attached for lifting purposes. On the top and bottom of this built-up casing cast-iron guide-plates are fitted, the method of attaching these and of accurately centering them with the body of the mould being clearly shown. A bottom steel face-plate D fits easily into the lower guide-plate, and, when prepared for casting, the upper surface of this face-plate is covered with burnt fire-clay segments $\frac{5}{8}$ inch or $\frac{3}{4}$ inch in thickness. A similar face-plate E, also faced with baked fire-clay segments, is carried upon the top plunger of the press, and fits easily into the upper guide-plate. The mould is lined throughout with narrow cast-iron laggings, the angles at the back edges of which are chamfered off so as to leave vertical passages up the back of the lags from top to bottom of the mould. Communication between the face of the lags and these vertical channels is afforded by grooves across the edges of the lags from back to front, while in the top and bottom guide-plates are grooves into which these vertical channels open. Holes drilled through the guide-plates into the grooves just mentioned afford free communication between the back of the lags and the atmosphere, for the escape of gases, vapours or metallic rain. During the operation of fluid compression gases continue for some time to burn from these vents, and a fine metallic rain also escapes from them. The cast-iron lags are lined with a highly refractory composition, from $\frac{5}{8}$ inch to $\frac{3}{4}$ inch thick, consisting of a mixture of rock ganister, old pots freed from slag, along with a little

FIG. 3.

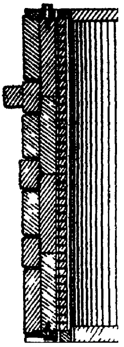
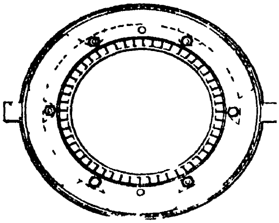


FIG 4.



Scale [illegible].

blacklead and china-clay. This mixture in a damp state is carefully applied to the surface of the lags, strickled and smoothed over its surface, and finally washed with a blacklead wash. After the whole has been carefully dried and warmed, the mould is placed in position ready for the reception of the metal.

The moulds just described are much more costly in first outlay than the cast-iron moulds, or wrought-iron casings previously spoken of, and they form an important and significant item in the first installation of the necessary plant; but the subsequent charges for labour, lags, &c., in the preparation of the moulds, does not exceed that incurred in the preparation of a cast- or wrought-iron mould lined with brick or composition; nor does the time occupied in the getting up of a mould exceed that necessary for the preparation of the ordinary lined mould.

THE HYDRAULIC PRESS FOR THE COMPRESSION OF FLUID STEEL.

In tracing rapidly the development of the hydraulic press as applied to the compression of steel, it is only intended to notice the more prominent features of the growth of the plant, which commenced about the year 1866, by the erection in the works of Sir Joseph Whitworth and Co., Limited, of a press with a cylinder 12 inches in diameter, capable of exerting a gross pressure of about 250 tons, and culminating by the Author's constructing and working at the Abouchoff Works, St. Petersburg, entirely with Russian labour and Russian manipulated materials, a press with a 50-inch cylinder, or 10,000 tons gross capacity, and which is one of the largest presses yet erected for this purpose. This machine made its first cast, exerting a pressure of 8,000 tons, before a large gathering on the 10th of October, 1878, since which date the press and its accessories have been and are at regular work to the entire satisfaction of those concerned.

Plate 1, Figs. 3, 4, 5, show the earliest press of Sir Joseph Whitworth, patented in 1866, which was erected in the works especially for the fluid compression of the steel required for armour-piercing steel shells. The first trials showed, however, that the pressures contemplated were totally inadequate, and that the idea of running the fluid metal into the mould, and then forcing into it a core having approximately the internal form of the shell, and lastly, of subjecting the metal to still further hydraulic pressure in such a mould was impracticable. This early press had two steel columns, upon which were cut over the upper halves of their length a series of parallel undercut V-threads or grooves. These columns were secured to a cast-iron base D, which carried a steel pressing-cylinder with its cast-iron ram P. Capable of moving over the upper half of the length of the columns, or of being firmly secured thereto, was a head E, which carried the hydraulic cylinder, ram and tackle for forcing the core, C, of the shell or hoop casting into the fluid metal, as well as the arrangements for closing the mouth of the mould containing the fluid metal. The ram in the upper head was capable of a vertical adjustment to suit the various lengths of cores, and the head itself could be raised or lowered by lifting arrangements connected with the shackle shown. In order to fix the upper head to the columns at any height, so as to receive the vertical thrust of the bottom or pressing-ram, split nuts, N N, were fitted to the columns, as shown in Plate 1, Figs. 3 and 4, and upon each half-nut were cast two lateral bosses, which were bored out and cut with screw-threads, the thread in the one half-nut being right-handed, and that in the other half-nut of each pair left-handed. Through these passed short horizontal shafts, screwed in a like manner, so that as the shafts are made to revolve in the one direction or the other, so the two halves of each nut either close together, so as to embrace the columns, or open out so that the head can be freely moved vertically, as may be required. The simultaneous movement of the four screws necessary to operate the two nuts was effected by fixing upon the end of each of the two horizontal shafts a spur-pinion, S, whilst a spur-wheel, T, is placed in gear with the two, so that, as shown in the diagram, a small movement of the hand-lever, L, and its connecting links suffices to open or close the nuts simultaneously.

Between the upper head E, and the lower head D, was a third head which, when in position for pressing, has its central vertical axis coincident with that of the core on the upper head and of the pressing-ram below. This middle head contains the steel mould, with its cast-iron lining, and inner coating of composition, as prepared for the reception of the fluid metal, and the head can be freed from one column and revolved upon the other as upon the post of a crane, Plate 1, Fig. 5. The head is thus revolved around the one column to receive its charge of fluid metal, after which it is revolved back over the top of the pressing-ram. The hydraulic ram in the upper head E then descends, and forces the clay-coated core C into the fluid metal, its upper facing also closing the mouth of the mould completely. The top ram, or core-plunger, is then locked with a split nut, worked by the hand-wheel W, shown in elevation, Plate 1, Fig. 3, and the higher pressure of the lower ram is put upon the metal. The duration of the pressure varied with the size of the casting; but, with a shell of 150 lbs. weight, Sir Joseph Whitworth stated that the pressure should remain on for about eight minutes, after which the core was withdrawn, but the end-pressure was continued until the metal was finally set, and sufficiently cooled to prevent damage arising from contraction, and the development of injurious internal stresses.

The next press was the much more useful, powerful, and successful arrangement, the special features of which are shown in Plate 1, Figs. 6, 7 and 8. The press, generally known as the Whitworth 2,000-ton casting-press, had two steel columns, traversed over the greater part of their lengths with a series of undercut horizontal grooves or threads. These columns were secured to a massive cast-iron foundation or base; surmounting the columns were cast-iron caps, on the faces of which steel plates were bolted to form the top head of the press. On this head was carried a heavy cylindrical iron casting, which itself supported a steel hydraulic lifting cylinder and ram. The lifting-ram was coupled by pins with lugs on the middle or movable head M, Plate 1, Fig. 8. The movable head could be raised or lowered as required by the upper lifting cylinder, and was arranged to slide freely along the columns, except when locked against them by the locking-nuts, N N. These were each made in two halves, and through two lateral bosses, B B, cast on each half-nut, was a screw-thread, right-handed in the bosses of one half, and left-handed in the bosses of the other half of each nut. Two horizontal shafts, screwed in like manner to fit the threads in the bosses of the locking-nuts, passed through the same, so that, according to the direction in which the shafts are revolved, the two halves of each nut are drawn together and fixed against the column, or are separated so as to free the column, and permit of an unobstructed vertical movement of the head. Keyed to the end of each of the screwed shafts is a spur-pinion S, and between each pair of spur-pinions is a spur-wheel, T. The latter revolves freely on a stud carried upon a slide, which permits of a slight vertical movement along a vertical plate carried upon the moving head. The boss of the spur-wheel, T, is prolonged for the insertion of four wrought-iron arms, constituting a hand-wheel, so that, whenever it is necessary to raise or lower the head, this wheel T is revolved, and with it the spur-wheels, and so the screws. In this manner the two halves of each locking-nut are separated, and their threads freed from the columns, whereby the head can be raised or lowered by the lifting-ram to any height corresponding to the varying lengths of the moulds; and then, by reversing the direction of rotation of the hand-wheel, the two halves of each split nut, N, are drawn together, and so made to embrace the columns, whereby further movement of the head is prevented. The pressing-cylinder with this press was 30 inches in diameter, and stood upon the base or foundation of the press; while the top plunger for closing the upper end of the mould was carried by the movable head as shown, so that in this, as in the other cases, the hydraulic pressure acted from the bottom against a top resistance. The method of casting, the manipulation of the press, the conduct of the pressing operations, and the phenomena observed, are practically the same with this press as with the larger ones to be subsequently described.

The success which attended the working of the last-mentioned press led to the design and construction, by Sir Joseph Whitworth and Co., of the larger or 8,000-ton press, Plate 1, Figs. 9, 10 and 11. This press has four steel columns, each 14 inches in diameter, traversed over the greater part of their length with a square screw-thread. The columns are secured to a massive cast-iron base, or foundation; and surmounting the columns is another cast-iron head for carrying the hydraulic cylinder used for lifting and lowering the middle or moving head. The top-head also carries the somewhat complex arrangement of wheels and nuts, shown in Plate 1, Figs. 9 and 11, for locking the movable head at any desired height upon the columns. The intermediate movable head is thus capable of vertical adjustment as may be required for the reception under the press, between the bottom pressing cylinders, and the top plunger carried on the moving head, of moulds of variable lengths. The lifting of the head is effected by a hydraulic cylinder carried upon the fixed head, the ram or piston P of which is coupled to the moving head M. Upon each of the main screwed columns is a locking-nut A, which can be arranged so as to revolve freely and automatically just clear of the head, as the latter ascends or descends. These same nuts when revolved independently of the moving head come firmly into contact with the head, and lock it securely against the columns during the operation of the bottom or pressing-rams. The method and mechanism for operating these locking nuts constitutes the special feature of this press, and it is as follows: There are two vertical quick-pitch screws B B, secured at one end to the movable head, while the other or free end passes vertically through long gun-metal nuts C, carried in the fixed head, Plate 1, Figs. 9 and 10. The nuts, C, are free to revolve, although they cannot ascend or descend through the head. They also form the elongated bosses of the spur-wheels

S, which in their turn gear into spur-wheels X, which slide upon a key in the vertical shafts L. One of these shafts passes through the top head, or table between the two end columns, and its lower extremity rests in a step on the moving head. To the lower end of each of these shafts, L, is keyed a steel spur-wheel, W, which gears into and rotates each of two similar wheels carried on the periphery of the locking nuts, whereby it follows that as the movable head is raised through the operation of the lifting ram P, the quick-pitch screws B ascend through, and rotate the nuts C, and with them the spur-wheels X, which in their turn drive the spur-wheels carried on the shaft L, and the rotation of the latter is transmitted to the locking-nuts A of the press, which thus rotate automatically at a fixed distance in front of or behind the head, according as the latter is ascending or descending.

In order to lock the nuts and hold the moving head in any position during the application of the pressure from below, it is necessary to rotate the locking nuts so that they shall come fairly into contact with the head, and this is effected through a band pulley Z, keyed to a horizontal shaft running across the top table, upon which are worms, U, gearing with the worm-wheels V, Plate 1, Figs. 10 and 11, the latter forming the head of a sleeve, which is screwed as shown on its outer surface, and through which the nuts C pass. Thus, by rotating the pulleys Z, and so the worms U, and worm-wheels V, the nuts C, the wheels S and X, the shaft L, and therefore the locking-nuts A, are all revolved through a small distance, sufficient to cause the nuts, A, to come firmly against the head. Rotation of the band-pulley Z in the reverse direction repeats the above movements, except in the reverse direction, so that the nuts C revolve in the opposite direction, and travel upwards from the head into a position where they are not in contact with the head, but are thus free to revolve when pressure is applied to the head to raise or lower it. This elaborate locking arrangement has been very much simplified in the presses subsequently erected.

To the lower side of the movable head is bolted the top plunger for closing the mouth of the mould, whilst the hydraulic pressure for the fluid compression is afforded through five hydraulic cylinders, namely, four cylinders each 28 inches in diameter, arranged around a central one 13 inches diameter. These cylinders all stand upon the planed surface of the foundation or base of the press, and operate against a solid cast-iron table or platform F, upon which stands the mould containing the fluid steel.

The 8,000-ton press last described remained for several years the representative of the most powerful press erected for the purpose, but it was placed second by the erection of a press at the Abouchoff Works, St. Petersburg, with 16-inch steel columns, and of 10,000 tons gross capacity. This press is shown in front elevation in Plate 1, Fig. 12, in end elevation in Fig. 13. Fig. 14 is a plan on the top side of the fixed head. Fig. 15 shows the top side of the table, pressing-cylinder and base of the press; while the details of the construction of the pressing-cylinder are shown in Fig. 5, p. 102. Like its predecessor this is a four-column press; its steel columns being 16 inches in diameter, secured by nuts to the heavy cast-iron foundation. The upper head is also of cast-iron, and carries the two lifting-cylinders, with their rams and cross-heads. From each cross-head hangs a pair of suspension rods, the lower extremities of which are coupled to the movable head of the press. The columns are screwed over the greater part of their length with a square thread. The locking-nuts N are of cast-iron, fitted upon their upper edge with a steel spur-wheel annulus, P. The revolving and travelling of these nuts along the columns automatically, in front of or behind the ascending or descending movable head as the latter is raised by the two lifting-rams, is effected by the two square-threaded left-handed screws S, which stand vertically and centrally between the end columns, and pass through gun-metal nuts B, in the tophead, Plate 1, Figs. 13, 16, while the other ends of the screws are prolonged through the movable head to a footstep Z, which thus receives the end thrust as the head is lifted. These vertical screwed-shafts S each carry a spur-wheel, K, which gears into a pair of wheels P on the periphery of the corresponding pair of locking-nuts. A vertical movement of the gun-metal nuts B, in the upper head, is prevented by shoulders on the top side, and by a disk or nut screwed on to its lower extremity against the lower surface of the head or table. On to the head of each of these nuts B is bolted a steel spur annulus Y, and these wheels respectively gear with the teeth on the two ends of a horizontal rack R R, Plate 1, Figs. 12 and 14, capable of movement through a short lateral distance under the action of a small horizontal double-acting hydraulic cylinder H, the ram or piston of which passes through glands in each end of the cylinder, and, by operating upon projecting horns on the above-mentioned rack R, can thus be made to drive the rack in either direction.

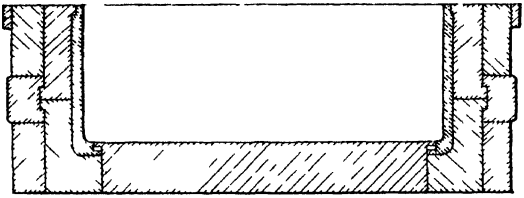
By the simple locking arrangement shown at L, Plate 1, Fig. 13, when the movable head is not resting upon the stops, shown around the lower ends of the columns, but is suspended at any vertical height along the columns, the pressure in the lifting-cylinders may be relieved, after tightly gripping the screwed-shaft S so that its revolution is prevented; since the head can be neither raised nor lowered unless these screw-shafts are allowed to revolve and ascend through the nuts B. The other details of the press are all simple, and the number of parts in the press is altogether exceedingly small.

The movement of the head, carrying as before the top plunger, is thus effected:—The locking-nuts N are first moved for $\frac{1}{4}$ inch or $\frac{1}{2}$ inch in front of the head, by the rack R, which is driven by the hydraulic piston H in the required direction, whereby the nuts B are revolved through a small arc; but, since the nuts cannot ascend upon the screwed-shafts, the latter are necessarily rotated to a small extent, and so also the wheels K which they carry, and hence the locking-nuts are rotated through the required distance. The nuts B are now held firmly by the hydraulic piston and the rack, so that, as the movable head is raised by the lifting-rams, the pressure between the ends of the screwed-shafts S and their steps Z, causes the shafts to ascend through the fixed nuts B; the shafts are thus revolved and so rotate the locking-nuts N, thereby keeping them regularly at the fixed and constant distance clear of the head. In like manner, when the movable head is allowed to descend, its weight is sufficient to cause the screwed-shafts S, and therefore the locking-nuts N, to revolve and hence to traverse the columns in the reverse direction, following the head at a constant interval. When the head has reached its final position, and its weight has been received upon the fluid metal, so that the latter is ready to receive the pressure from below, it is necessary to lock the head in that position; for this purpose the water-pressure is admitted to the opposite side of the top hydraulic piston H, so as to move the rack, the wheels, nuts, and screws in the opposite direction as required to rotate the locking-nuts N, into firm contact with the face of the movable head, under which conditions the pressure from below cannot afterwards raise the head.

Around the lower ends of the columns are bolted cast-iron stops, upon which the head is lowered and rests when not at work. Unlike the other presses, this has a single pressing-cylinder and ram notable for its large diameter, and for the high pressure at which it works. The cylinder, which is 50 inches in internal diameter, is built up, Fig. 5, of steel hoops after the usual manner adopted in gun construction, and is lined with a gun-metal liner, the bottom being inserted from the inside. It constitutes, so far as the Author knows, the largest high-pressure hydraulic cylinder hitherto constructed. The cylinder stands upon the planed surface of the base of the press, and the water from the pumps or accumulator is admitted to it simultaneously through a pair of pipes on opposite sides of the cylinder.

In working this press, an accumulator, loaded with cast-iron plates, so as to produce a pressure of 2 tons on the square inch, gives the rapid movements of the head of the press, of the lifts, cranes, &c., required during the manipulation and movements involved in the transference of the metal from the furnace to the mould, and of the mould itself beneath the press. The engine employed at the Abouchoff Works was a simple high-pressure non-condensing engine, of German make, intended for other work besides driving the pumps. The power was taken by a belt from the rim of the fly-wheel, 12 feet in diameter, on to an 8-feet pulley on the pump-shaft, as shown in the general plan (Plate 1, Figs. 1 and 2).

FIG. 5



SECTION OF CYLINDER OF 10,000-TON PRESS

Scale [illegible]

The pumps are also capable of being thrown out of gear, so as to liberate the engine. The pumps are of forged steel, six in number, with rams of 2¼ inches diameter and 4½ inches stroke, placed in two parallel rows on the top of a rectangular casting, which forms also the reservoir from which they take water. Between the two rows of pumps is a three-throw eccentric or crank-shaft, driven by gearing from the engine-shaft. The eccentric shaft gives a reciprocating motion to three sliding blocks, from which a pair of links passes to the front end of each pump-ram, in such a manner that, whilst the pumps are at work, it is easy to disconnect any one or more rams, according as the demand for water decreases, or repairs become necessary.

The Author has not considered it desirable to burden this Paper with any description of the presses, nor of their action, in which two or more hydraulic rams were designed to operate simultaneously upon various points of a casting, such as a trunnion, or other forms which are not quite regular in shape. Such contrivances have met with only limited degrees of success, and, so far as the Author knows, have been generally abandoned in favour of a direct pressure acting upon the regular cylindrical form of ingot.

In leaving the description of the plant, it is scarcely necessary to remark that the designs were carried out and framed to suit particular circumstances, the facilities and nature of the general surroundings, and largely, the predilections of the paymaster. Admirably as the plant has fulfilled its requirements, yet in new designs material modifications would be effected in the proportions, detailed mechanism, and even general form of the press.

General Arrangements of the Plant at the Abouchoff Works.

The method of working the plant will probably be best understood after a consideration of the general arrangements of the plant, Plate 1, Figs. 1, 2, which are a plan and vertical elevation (partly in section), respectively of this part of the Abouchoff Works, and which the Author hopes are almost self-explanatory. The press, P, stands in the centre of the steel-melting departments, consisting here of open-hearth furnaces, a crucible-steel department with coke-fires, and a department for crucible steel melted in gas-furnaces. It was thus in a position to receive the metal from any of these departments. In front of each of the Siemens furnaces is a circular pit, served by hydraulic and swing cranes, for manipulating the moulds, &c., into which the metal is put when not required at the press. For pressing purposes, the steel is tapped from the open-hearth furnaces into the ladle, which is traversed along the rails by the hydraulic capstan C, to the turn-table T, from whence it passes along other rails, over the mould, which stands upon the hydraulic lift L, ready for the reception of the metal. There is a lift upon either side of the press, so that the steel from the furnaces B, or from the crucible department, can pass directly to the moulds placed on opposite sides of the press. In the long casting-pit, Plate 1, Figs. 1 and 2, is shown, standing in position upon its bottom block, an ordinary chill mould, M, ready to receive a charge when the metal is cast in the ordinary open-topped mould without the application of pressure. The Figs. also show the position of the engines, pumps, accumulator, and the arrangement of pipes between them and the press, valve-house, &c. The main pipes are all of forged steel, 4 inches in diameter, bored at the works, and coupled together, principally with screwed sleeve-couplings. The valve-house contains a horizontal cylinder, connected directly with the pumps, and upon which is a lever safety-valve, as also a pressure-gauge. Connected to this cylinder are all the valves and supply-pipes to the various parts of the press, lifts, cranes, rams for moving the moulds, &c., whereby a single attendant can control the whole of the movements between the tapping of the metal into the mould, its insertion under the press, and the conduct of the pressing operation. The house also serves as a protection against the showers of sparks, &c., that frequently escape with considerable violence during the pressing of the fluid metal.

This department of the works stands on low-lying ground close to the River Nova, and the foundations are accordingly swampy and always filled with water. The press and lifts are therefore carried upon wooden piles, supporting a light masonry foundation, upon which the base of the press is fastened, by bolts passing through the stone-work to girders beneath.

Of the two lines of pipes coming from the pumps to the valve-house, the one ultimately connected with the further end of the distributing cylinder in the valve-house passes alongside the press, where a valve is placed, by opening which the water will pass directly from the pumps to the large pressing-cylinder; or by closing this valve the water then flows onwards past the press to the cylinder in the valve-house, from whence it is distributed, as before mentioned, to the several cylinders as required for the different movements. During the actual pressing operation, the large cylinder of the press is in direct communication with, and receives all the water from, the pumps, unless the workman watching the mould and the pressure-gauge observes that the pressure is rising too high, or with too much rapidity for the particular ingot under operation, when he opens a valve in the valve-house by which the water is allowed to run to waste, and the pressure thus reduced.

CONDUCT OF THE PROCESS OF FLUID COMPRESSION.

In the conduct of the operation, the mould having been duly built up, lined with refractory materials, carefully dried and warmed, is placed in position upon the heavy cast-iron table, which stands for its reception upon the platform of the hydraulic lift, upon that side of the press from which the molten metal is to be received. The whole is then raised until the platform stands level with the rails between the columns of the press. By means of the horizontal ram R, Plate 1, Fig. 2, the table and mould are next transferred beneath the press, during which motion the platform of the hydraulic lift rests upon four stops, which fall automatically into the proper position as the lift ascends. The mould is now carefully adjusted and fixed by lugs, so that it stands quite fair and concentric with the top plunger carried on the movable head of the press. This being effected, the operations are repeated in the reverse order, the mould is drawn back by the ram R on to the lift, which is then lowered to such a point that the top of the mould will stand just below the nozzle or tap-hole of the ladle, in which position it awaits the arrival of the fluid metal. The ladle containing the molten metal from the furnace is now run over the top of the mould, and the metal tapped out in the usual manner. The ladle is afterwards quickly run back from the face of the press, and the mould with its charge is raised to the proper level, so that, when the lift rests upon the four dogs just referred to, the horizontal hydraulic ram R advances, and pushes the mould and its carriage beneath the press against the already adjusted stops. When all hands have retired, the single attendant in the valve-house lowers the head of the press, until the top plunger is fairly in contact with the fluid metal in the mould, such contact being usually marked by a more or less abundant expulsion of metal from the top of the mould; but, the top face-plate being only about $\frac{1}{10}$ inch less in diameter than the top guide-plate of the mould, the clearance is thus about $\frac{1}{20}$ inch all around, between the ram and the mould, and this is quickly filled and made into a tight joint by the chilling of the fluid metal as it escapes through that space. The head of the press, weighing about 50 tons, will for some seconds descend slowly upon the fluid metal; after which the movable head is locked in position by another valve, revolving the locking-nuts into firm contact with the head. All this is the work of only a few seconds, when the main valve alongside the press is opened, and the water passes direct from the pumps into the lower or large pressing-cylinder. The pressing-ram is moved up as rapidly as possible, so long as the fluid metal can be kept within the mould. A too rapid movement in the earlier stages is quickly indicated by the escape of metal from the vents, and from around the edges of both the top and bottom plates of the mould.

The attendant in the valve-house promptly responds to an escape of metal, by very slightly depressing the lever which he holds in his hand, and thereby allows the water to pass to waste for a few seconds only. The ingot shortens rapidly during the first few minutes of the process and the maximum pressure which it is intended shall operate upon the ingot is attained as quickly as possible. After the first few minutes, but varying with the size of the ingots, the rate of reduction in length gradually decreases until, as the operation approaches completion, the shortening per minute has become very small or has ceased altogether. As the rate of shortening becomes less, a larger amount of water must either be allowed to run to waste, or as is more usual the speed of the engine is first reduced, and then the supply from the pumps is diminished by uncoupling two, three or more pump-rams, which can be effected whilst the machinery is in motion.

The closing of the top of the mould and the application of the pressure are at first attended with a large evolution and escape of combustible gases, which burn copiously in a series of jets, which from their roaring character are obviously under considerable pressure. These jets of pale blue flame, which appear at the vent holes and around the joints of the plates and the mould, at both the top and bottom of the casting, were formerly attributed wholly to the combustion of carbonic oxide; but from more recent observations the Author concludes that at least a considerable proportion of hydrogen is present, whilst the amount of such escaping gas is certainly much more than can readily be conceived to arise from the expansion of atmospheric air enclosed in the interstitial spaces of the mould and its lining, or to any chemical reactions going on in the material of the lining under the influence of heat and the pressure applied. Not unfrequently, after the full pressure has been maintained for some four or five minutes, or upwards, there will be one or more violent explosions accompanied by loud reports, along with the ejection of sparks, shots and fine rain of metal in profusion; the exit for such matters being in these circumstances obtained sometimes from the top, and at other times from the bottom vents and joints of the cover of the mould. That such explosive ejections are due to the escape of gases, previously pent up within the metal, appears to the Author to be confirmed from the fact, that they are always accompanied by a loud report, the result of the sudden expansion of gaseous matter; and also that, if the attendant be sufficiently prompt on these occasions in opening the valve to waste, he can often prevent any stream or large volume of metal from being ejected, under which circumstances the explosions are accompanied by little more than a fine rain of metal and dust. Even when there has been an absence of all explosive action, the fluid compression is accompanied by a fine rain of metal which is carried out with the escaping gases and deposited on the top plate of the mould.

The pressure is continued long after the visible escape of gases and rapid shortening of the ingot have ceased, or otherwise the metal in cooling might be exposed to severe internal stresses, which might result possibly in the production of cracks and fissures, and even fractures such as occur occasionally with unpressed ingots. These internal stresses are met, however, and taken up to a very considerable extent by the external pressure applied to the metal during compression, so that as shown by the experiments of the late General Kalakoutsky, I.R.A., the pressed ingot, although not free from initial and injurious stresses, is to a less degree under the influence of such stresses than even many forgings are. Hence another cause for the immunity enjoyed by fluid-compressed ingots from the cracks, or fissures often produced, either explosively or otherwise, during the cooling down of ingots cast in open moulds without pressure. The maximum pressures attained during the process of fluid compression as usually conducted, and tabulated in Appendix IX, are from 4 tons to 12 tons per square inch upon the upper surface of the ingot; but, unless such pressures are maintained for a sufficient length of time, there will be a perceptible weakness along the axis of the ingot as compared with the best portion of the metal, such as will be observed in the 34-inch ingot, the subject of this Paper. Examples 2, 3, 4, 5, 6 and 7, Appendix IX, also show the influence of time in producing homogeneity of the metal. The ingots referred to in those cases were of the same class of metal, and subjected to the same pressure of 11·11 tons to the square inch, but were improved in soundness and homogeneity just as the duration of the pressure was increased. In No. 2, the pressure operated for only thirty minutes, and on parting the ingot a small pipe was visible; Nos. 3, 4 and 5 were under the pressure for thirty-three, thirty-six and thirty-seven minutes respectively, and showed practical soundness, or at most but a slight sponginess along the centre; but a pressure of 1¼ ton on the gauge, 13·88 tons per square inch on the metal, continued during forty-two minutes, always resulted in the production of sound ingots. The same result is attained with the even lower pressure of ⅞ ton on the gauge, 9·72 tons per square inch on the metal, when that pressure is maintained during fifty minutes as in the example No. 7. The time necessary to ensure solidity depends obviously upon the size of the ingot; the larger the ingot and the longer in cooling down, the longer will be the time during which compression will be effective; thus with the 34·25-inch ingot, the metal was under the pressure continuously for three hours and a half. The remarks placed opposite the other items of Appendix IX are, the Author hopes, sufficiently lucid not to call for further explanation.

In taking leave of the Tables constituting Appendix IX, it is to be noted, however, that the figures there tabulated may be taken as representative of the ordinary practice. The figures are selected from some hundreds of records, embracing casts from both open-hearth and crucible steel, and are made upon tempers ranging from 0·3 per cent. to upwards of 1 per cent. of carbon, all of which are, however, practically only repetitions of the same figures and remarks.

The shortening in length of the ingots, measured between the lengths when fluid, and on removal of the ingots from the mould after pressing, usually amounts to 1½ inch per foot. The shortening of the 34·25-inch ingot especially referred to, and cast under the lower pressure employed in that case, amounted to $8\frac{5}{16}$ inches, the finished length being 70·2 inches. The shortening was thus slightly under the average owing to the lower pressure employed, and hence also the weakness along the axis of the ingot as shown by the test-pieces cut from the centre, which weakness is always less marked as the pressures employed are higher.

Sir Joseph Whitworth, in his evidence before the registrar on his application for the prolongation of his patent,[1] said .—"When the pressure is applied to a column of fluid metal, whether it is solid or whether it is the shape of a tube, in five minutes after the pressure is applied, the whole mass, whatever its height, will go down one-eighth of its whole length, the air being pressed out," and he subsequently stated that "not less than 6 tons on the square inch is required."

Although pressures of from 4 to 6 tons and upwards per square inch on the fluid metal are usually employed, yet, when the metal is well cast, the pressure quickly applied, and maintained during an adequate time, sometimes even less is sufficient to ensure the practical soundness of ingots, and to give to the metal increased ductility, homogeneity, and reliability for any temper of the steel. But in order to ensure that the tests from all parts of a pressed ingot shall give practically uniform results, except so far as local chemical composition and liquation of elements affect such tests, a pressure of from 12 to 15 tons per square inch on the metal is desirable. Metal pressed under such conditions, and then carefully annealed, had always, in the Author's experience, afforded within practicable limits uniform results over all sections of the ingot.

---

[1] Evidence of Sir Joseph Whitworth, Bart, in the matter of his petition for prolongation of letters patent, 1879

CASTING OF HOOPS OR HOLLOW INGOTS.

The casting of hollow forms was for many years in practical operation both in England and in Russia, but such forms have been generally abandoned. A better material, and on the whole a more economical production of hollow forgings, is obtained by casting the ingot solid, then boring out the centre, and afterwards treating this bored ingot as though it were a hoop casting. Examples of the pressing of such hoop forms are given in Appendix IX. The idea of casting hollow regular forms, instead of solid cylindrical ingots, may not be amiss; but the practical difficulties and increased risk arising from the mechanical introduction of foreign matters, sand, &c., into the metal, more than compensate for any advantages that would otherwise arise from the adoption of the hoop form. The cost of preparing cores, the time and occasional difficulty in getting them out, together with the fact that under insufficient pressure the line of weakness is transferred from the axis of the ingot, where it is of little importance for most applications of the steel, to a cylindrical surface along the length of the ingot at about the middle of the thickness of the hoop, or midway between the internal and external diameters, in which position for many applications it might become a serious disadvantage, constitute drawbacks. In designing the hoop form of ingot the intention was to arrange the proportion of steel in the casting to the metal in the core; so that, whilst the latter should be sufficient to withstand the compressive stresses produced under the pressure necessary to ensure solidity of the metal, the mass of the core should not exceed that which would by conduction attain to a red heat, in the time occupied by the fluid steel in cooling down to that temperature. The steel hoop and its cast-iron core would, under such conditions, contract during cooling uniformly and together, towards the centre, and without introducing injurious contraction stresses; or by making the core with a hole along its axis, water could be passed through it, and the casting thus cooled from the centre instead of wholly from the outside. Hoops need proportionately smaller pressures than ingots in order to ensure soundness. The solid ingot, as it leaves the mould after compression, is usually clothed with an indurated, siliceous jacket (for the sand lining of the mould generally follows the ingot and leaves the lagging of the mould almost clean), which jacket, as the ingot cools, is left as a loose outer shell, which breaks away under the hand-hammer; in the case of the hoop casting the outer surface is also left perfectly clean in like manner. But with the inside of the hoop the case is different. The indurated coating of the core remains, and is there more and more tightly embraced as the metal cools. It thus often becomes difficult to clear out this siliceous lining before commencing to forge such castings upon the mandrel. These practical difficulties, in conjunction with figures to be presently cited, show the wisdom of the practice now invariably adopted where fluid compression is in operation, of casting only solid ingots, and then, if the hollow form is necessary, boring a hole along the axis of the ingot. The tests demonstrate that, after such treatment, the homogeneity of the metal thus left, even after every inch in length of the pressed ingot has been taken, is superior to the best portions of an ingot cast in the ordinary manner without pressure; and further that such metal, when forged upon a mandrel for the production of ordnance forgings, shafts, hoops, and hollow forgings generally, yields an article which common repute, and steel users like General Maitland, Mr. Wright, Mr. Hotchkiss, and others, accept as superior to that produced by any other method. Thus General Maitland, C.B., says,[1] "The Whitworth speciality is of high excellence, and as a rule the castings are very sound." Mr. James Wright[2] said, "Since the Whitworth metal had been employed for parts of marine engines in H.M. ships, there had not been a failure of anything whatever composed of Whitworth metal." Mr. B. B. Hotchkiss "began to use fluid compressed steel in 1871, and had had between 1,600 and 2,000 barrels. He had never had a failure with it." At the same time it was stated that not one of four hundred air-vessels supplied to Woolwich had failed, although previous vessels made of ordinary steel had failed under the tests.

EFFECT AND ADVANTAGES OF THE FLUID COMPRESSION OF STEEL.

Solid ingots, free from visible honey-comb or blow-holes, can be, and are, daily produced when fluid steel is submitted to the necessary pressure, and in the manner described, hence questions arise as to what are the effects of such treatment of the fluid steel upon the quality of the metal so compressed; and how these effects have been produced. It may be convenient to defer the direct and tangible results in the shape of proof of improved quality of material, and of greater yield, &c., from the furnace output, due to the saving of head or top end of the ingot, and by the reduction of the allowance for turning, boring, planing, or other machining of forgings to a minimum, in order to first enter upon the domain of speculation involved in the second question. Though at present a matter for surmise, the Author is not without hopes that, at an early date, experimental proof may be forthcoming to show what is the manner of action of hydraulic pressure when applied to fluid steel.

---

[1] The Journal of the Iron and Steel Institute, 1881, p 429

[2] Notes of Evidence on the hearing of Sir Joseph Whitworth's petition for prolongation of his letters patent.

Most persons are prepared to accept the fact that honey-comb, blow-holes, contraction cavities, or other unsoundness, prevail in steel ingots whether cast in ordinary chill, in brick, or in cement-lined moulds; and that the cells within such ingots are of two classes, namely, (1) Cells filled with gases, principally hydrogen and nitrogen, with small amounts of carbonic oxide and carbonic anhydride, such gases being in high tension, as inferred from the large volume of gases at atmospheric pressure and temperature which these cells frequently yield. (2) Other contraction cells, possibly more nearly vacuous, the result of the shrinking of the interior after the outer skin of the ingot has become solid and unyielding. (3) The ingot, as cast in the ordinary manner without pressure, is also frequently rendered weak, by the development during cooling of a radial acicular structure from the surface of the ingot towards the centre, even though there are no visible bubbles or cavities about that part of the section.

Under the enormous external pressures applied during fluid compression, the development at the surface of the weak acicular structure is prevented; and further, it does not appear difficult to conceive that a sufficient intensity of pressure would always be transmitted through the fluid or viscous, and always highly-heated, metal, as would suffice to reduce in size, and ultimately close the contraction cells, or such cavities as may be devoid of gas, until their unoxidized surfaces come into direct contact, and absolute molecular continuity is ensured. The Author considers it more probable, however, that the internal stresses developed during cooling, and under which the contraction cells tend to form, are met in the first instance by the external pressure; and that thereby the fluid or viscous metal is prevented from evolving its occluded gases, as it otherwise would do; and hence that the formation of such cells is impossible under a properly conducted method of fluid compression. But, where either the pressure is slow in its application, is of insufficient duration, or of inadequate intensity, he is of opinion that the formation of these contraction cells would be only partially prevented, and that hence would arise some of the imperfections observed along the axis of imperfectly pressed ingots. That this theory is correct would appear also to be confirmed by the investigations of the late General Kalakoutsky,[1] which show that the injurious internal stresses in a fluid compressed ingot are inconsiderable as compared with such stresses as occur in a 9-inch gun cast with internal cooling; or to the stresses in the breech end of the rough-turned, bored, and annealed forging for an ordinary 11-inch Krupp gun.

As to what becomes under compression of the blow-holes, which are filled with gases in the unpressed ingot, two theories are often advanced; the one asserting that the gases are mechanically driven out, and the mass of the metal so closed up; while the other concludes that the gases are reabsorbed (occluded) by the metal of the pressed ingot; or that, like the contraction cells, their formation never takes place in the pressed metal, owing to the pressure being sufficient to cause the retention of the gases in the occluded state. It is difficult to prove which of these theories is correct; but the Author is of opinion that there is at least a very large expulsion of gas from the metal by the pressure applied externally, since during the operation of pressing an exceedingly fine rain of metal continues to escape from the vent-holes, obviously carried out from the ingot by the escaping gases. The volume of combustible gaseous matter, which escapes from the vents around the ingot-mould, is also much greater than can be conceived to result from any expansion of air occupying the channels in the moulds, or from the decomposition of water and organic matter derived from the thin sand lining of the same. The examination of imperfectly pressed ingots shows also, that at the close of the pressing operation the gases have a tendency, like the carbon, silicon, sulphur, phosphorus, &c. in the steel, to concentrate themselves towards the axis and top end of the ingot, but more particularly along the axis; and this would seem to indicate that, after exit for gases from the surface has been closed, the remaining gaseous bubbles either circulate towards the more fluid central portion of the ingot; or otherwise such fluid metal, under the high pressure to which it is submitted, acquires a much greater power of occluding gases than it possesses under ordinary casting conditions; and that only along the centre line of the ingot, where the transmitted pressure would be lowest, and where the metal would be the last to solidify and cool, does the transmitted pressure fall low enough to admit of gaseous evolutions, and the formation of a funnel-shaped pipe, or of an axial zone of spongy porosity. But be the explanation what it may, while the unpressed ingot presents an irregular distribution and considerable volume of blow-holes throughout the upper third of the ingot (Fig. 1, p. 87), the insufficiently pressed ingot only presents either an elongated pipe or sponginess along the upper end of the longitudinal axis, or very frequently the residual blow-holes are concentrated into a single elongated more or less pear-shaped chamber, near the top of the ingot, the bubbles not so collected together being usually very small, few in number, and extending for but a short lateral distance from the central pipe or chamber. Accepting this tendency of the gases to collect in a single cavity, while the fluid compression is operating, only one step further is necessary to eliminate the gas completely, either from the top or the bottom of the mould, and that may possibly be presented during the violent bursts that frequently happen during the compression process. It is quite usual, after the pressure has been operating for some time, and the volume of the ingot has considerably decreased without any explosive violence being manifested, that as the pressure rises towards its maximum intensity, such increase is attended by a violent explosive expulsion of gas, accompanied by more or less metal. Such escapes sometimes take place from the top vents, and at others from the bottom vents. May not these explosions, then, mark the final expulsion of the gases from this central pipe or chamber, after the outer metal of the ingot has partially solidified, but yet not so completely as to prevent its being permeated or burst through by the gases, under the increasing pressure to which they are here subjected?

---

[1] "An Investigation into the Internal Stresses occurring in Cast-Iron and Steel." General Nicholas Kalakoutsky, I.R.A.

It matters not, however, except as a subject of scientific interest, how the unsoundness is removed, so long as the process is successful in producing for the engineers' use ingots which are free from blow-holes, have an increased ductility, higher elastic limit, greater tensile-strength, and enhanced value per ton, besides saving the waste and annoyance arising from the casting and use of unsound ingots. But if the Author is right in his speculations, the first effect of the application of hydraulic pressure to the fluid metal in the mould would be to consolidate the metal by closing up, or possibly preventing the formation of, the honey-comb and acicular structure found in ordinary unpressed ingots over their surface, extending, in a 34·25-inch ingot, to a depth of

2½ inches and upwards from the skin (Fig. 1), the gases from such cells escaping through the lining of the mould, as being the direction offering least resistance to their passage. Then, as the pressure increases, the further separation of occluded gases within the mass of the metal is either partially or wholly prevented, while other distributed bubbles of gas are driven in part outwards, but to a greater extent towards the more fluid or central portion of the ingot, to be finally re-absorbed or ejected through the still highly heated and permeable metal, under pressures of from 5 to 20 tons per square inch, to which the metal is ultimately subjected. Further, by continuing the pressure upon the solidifying and contracting mass of metal, the formation of contraction cells, which would otherwise occur towards the top and along the axis of the ingot, is prevented, and no visible record of them remains. It may be here noted that, if the gases hydrogen and nitrogen be not expelled or re-occluded, but only compressed into smaller volume, then, according to recent investigations,[1] under a pressure of 3,000 atmospheres the volume of hydrogen would be decreased from unity to 0·000964, and the nitrogen from unity to 0·001446, all at 15° Centigrade; and if this decrease can be effected without leaving injurious internal stresses within the metal, it must be accepted as a long step towards soundness. That the internal initial stresses within the pressed ingots is small is shown from the investigations of General Kalakoutsky, already referred to (p. 112), and in further proof of this it is noticeable that the Author has never known a perfectly pressed ingot to be cracked when removed from the mould, or to crack when introduced into the furnace for re-heating; while most manufacturers of large steel ingots have occasionally an unfortunate experience of both of these phenomena.

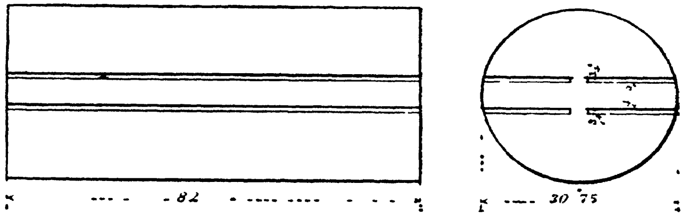
But besides external cracks, ingots of large diameter, cast in open moulds and cooled in the air, occasionally develop large and serious internal longitudinal and radiating cracks along, or from the centre, especially towards the upper end. Such defects are obviously the result of the action of excessive tensile-stresses acting upon the interior of the ingot, during cooling, and after the outer surface of such ingots has become solid, while at the same time, and from the same cooling agency, the external skin is under compressive stresses. With fluid-compressed ingots, however, such defects do not appear, since these stresses are to a large extent neutralized by the external pressures applied, such pressures being always continued as long as any alteration in form is observable. In like manner, even after considerable care has been exercised in the heating of large ingots for the forge, cracks are occasionally present in unpressed ingots; but during the past ten years' working of the compression process the Author does not recollect either having seen or heard of a single defect of this class in ingots of fluid compressed steel; and it is notable that, owing to the immunity from the accidents referred to, much less care and anxiety are manifested alike by masters and men when re-heating, hammering or forging by pressure, the ingots of fluid-compressed steel.

---

[1] Mr. E H Amagat, 'Comptes Rendus de l'Académie des Sciences,' 1888, vol. 107, p 522.

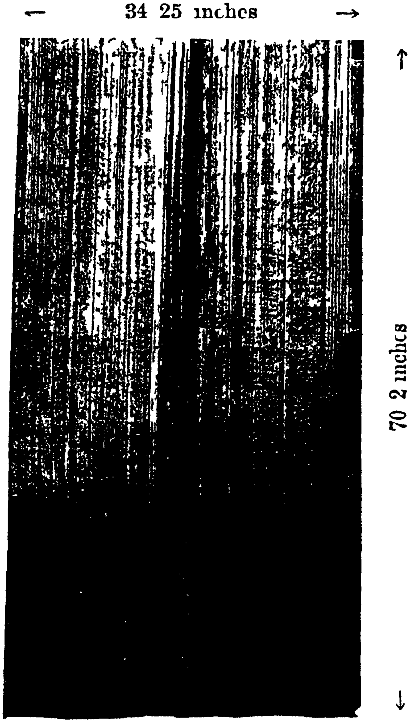
Passing now to an examination and comparison of definite examples of the two methods of casting, Fig. 1, p. 87, represents a longitudinal section of an unpressed ingot of open-hearth steel, cast in the usual way in an open-topped mould. The ingot was 30·75 inches in diameter, 82 inches long, and weighed 8 tons. It was cast with every care, and subsequently placed on a planing machine, where it was parted into a central plate 4·75 inches thick, and of the full length and width (equal to the diameter) of the ingot, and into two side segments (Figs. 6). The three pieces were then placed vertically alongside of each other and photographed. It is only necessary at this stage to observe that the upper 34 inches of the length of the ingot, out of a total of 82 inches, was useless for the purposes of a gun-forging, and no part of this 34 inches was tested for tensile-strength. To compare this with an ingot of fluid-compressed steel, an ingot, also of about 8 tons weight, was cast, 34·25 inches in diameter (the nearest diameter of mould in stock for a pressed ingot), and 70·2 inches long after compression, 78·5 inches long before compression (Fig. 7). This ingot was treated exactly as the preceding one, and three similar pieces were obtained, upon the surfaces of not one of which was a sign of honey-comb or blow-hole visible; and whatever may be the practice elsewhere, this is the regular result of the working of the method of fluid compression at the Abouchoff Works. During the Author's direct responsibility

FIGS 6.



at those works, and especially during the earlier period of the working of the process, large numbers of ingots were cut up for examination and demonstration of the value of the process. The high results of such examinations exceeded previous experience and expectation, the invariable experience being that the ingots presented either no visible cavity, or only perhaps an axial pipe or porosity into which a pin or wire might be inserted. Accordingly, instead of casting an ingot of fully 30 per cent. greater weight than was necessary to produce a required forging, it became, and is now the practice, to cast ingots as near as possible of the net weight required for the forging, providing only for the usual waste and for the amount to be turned off, but without allowance for top end of the ingot. Further, the occurrence of roaks and seams in

Fig 7



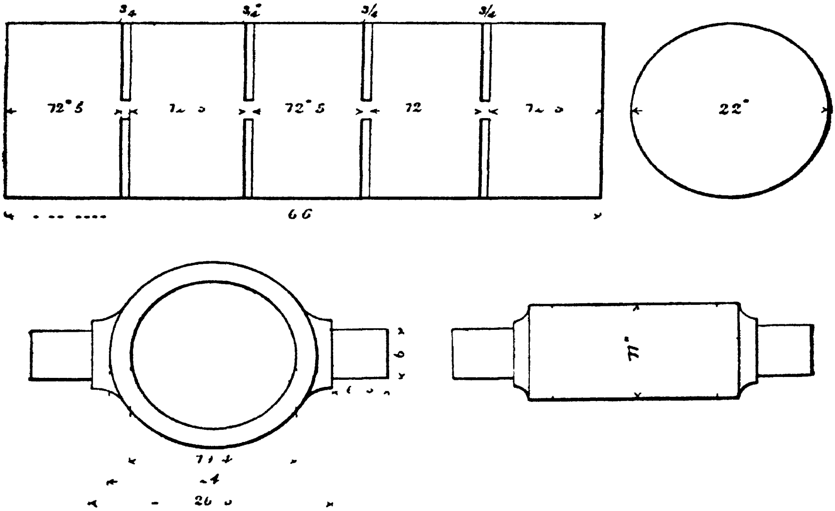
Slab 4 95 inches thick, taken longitudinally from centre of 8-ton pressed ingot the forgings, instead of being usual, are with fluid-compressed metal comparatively rare and of very minor importance, whilst rejections on account of faulty metal have become exceptional, and this notwithstanding that the entire weight of metal as cast is used for the forgings.

The freedom of rolled and hammered bars from roaks and seams is for special applications of exceeding importance; and it is within the Author's knowledge, that to ensure this with ordinary ingots, as much as 30 per cent. of the metal has been turned away from the surface of the ingots in order to remove the surface honey-comb before commencing to hammer or roll the metal; whilst the same orders have been fulfilled with equally clean bars from fluid compressed metal, without the preliminary loss in material, labour and time involved in turning down the ingots.

The advantages and saving of material, arising out of the use of compressed metal, will perhaps be more forcibly illustrated by a case in point. In the manufacture of trunnions for 6-inch breech-loading guns, the practice at the works, before the introduction of fluid compression, was, to cast for the purpose ingots of 65 cwt. each, and to forge from each of such ingots three trunnions; and it was considered satisfactory if not more than one of the three forgings had to be rejected on account of original unsoundness of the material. With the introduction of fluid compression the same weight, 65-cwt. ingots, measuring 66 inches in length and 22 inches in diameter, is employed. The ingot is cut under the hammer (Figs. 8) into five equal lengths each 12½ inches in thickness; and each is then forged into a trunnion. The five trunnions so obtained weigh in their finished forged state 52 cwt., the only loss between the cast ingot and the forged weight being due to punchings, cuttings, and furnace waste during the forging; and further, a rejection owing to defective material is unknown, although large numbers of trunnions are annually made. Another instance of the economy is the production of two trunnions for 12-inch breech-loading guns from a fluid-compressed ingot 38 inches in diameter, and only 48 inches in length. Such an ingot weighs 146 cwt.; it is cut evenly into halves, and then each piece is forged under the hammer into a trunnion, weighing 59 cwt., as a finished forging. To make two such forgings from an unpressed ingot, with a reasonable hope that neither of them would be rejected, under the rigid inspection to which these forgings are subjected, would require an ingot cast in the ordinary fashion to have double the weight of the pressed example. A further advantage attending the use of the pressed metal, is, that less margin is allowed for turning off, since rokes and seams have not to be contemplated. With larger, heavier, and special forgings, the advantages of fluid compression are still more marked, but the last examples have been selected since they are regular and repetition work, which thus permit of more extensive comparisons.

Finally, reference should be made to the oft-repeated question: How does the density of compressed steel differ from the steel cast without compression? The Author believes the answer might be anticipated; for there does not appear to be any reason why steel, compressed in large masses, should yield a metal of notably higher density than a piece of sound metal taken from the bottom of an ingot cast in the ordinary or any other manner, provided that there be no variation in the chemical composition in the several samples. If the density of ingots, taken as a whole, be considered, then the pressed ingot has a much higher density than the unpressed ingot; but, if only sound specimens be selected from each of the two ingots, the variation will be small. Dr. Percy and Sir Henry Roscoe are reported to have returned 7·8438 and 7·841 respectively, as the specific gravities of samples of compressed steel submitted to them. The Author's determinations were made upon crucible metal from one charge containing 0·54 per cent. of carbon, but cast partly in a chill mould and partly into an ingot subjected to fluid compression; afterwards samples were taken from the lower end of the ordinary ingot to ensure soundness. The specific

FIGS 8



gravities of the specimens were 7·8542 for the unpressed metal, and 7·8791 for the fluid-compressed metal; and this latter value was practically confirmed by one of the Author's assistants, who, with samples taken from different parts of the section of a 5-ton hoop casting, reported 7·8772, 7·8789, and 7·883, as the specific gravity of the fluid-compressed metal.

Tensile-Strength, &c.—Favourable tests and exceptionally satisfactory results are always expected from the testing of fluid-compressed steel. It is usual to state that such metal is some 18 per cent. stronger under a tensile-stress than the metal made without fluid compression. Exact proof of this, however, the Author finds difficult to obtain; since, even with the great mass of data and eighteen years' experience at his disposal, he has not been able to discover a parallel series of tests which would directly show this, as it involves the preparation of a large number of comparative tests upon unforged ingots from the same charges, pressed and unpressed, so that the metals under comparison shall be of identically the same composition, made from the same materials, and under precisely the same conditions. The unpressed samples also must be quite sound, otherwise for this determination the results appear almost worthless.

The following Tables of average results, calculated from the detailed Tables of Appendix V and Appendix VI, show that although the unpressed ingot is of somewhat harder temper than the pressed ingot, yet the elastic limit, the ultimate breaking-strength, the contraction in area at point of fracture, and total elongation before fracture, are all higher in the fluid-compressed metal than they are from the metal of an uncompressed ingot; even where the comparison is made with the average over the whole ingot in the compressed metal, as against only the best or lower two-thirds of the unpressed ingot.

COMPARISON of the AVERAGES of the FIVE SERIES of LONGITUDINAL TESTS from an UNPRESSED CAST INGOT, with the AVERAGE of the CORRESPONDING SEVEN SERIES of TESTS from the PRESSED CAST INGOT, as DETAILED in APPENDIX V.

—	Average or Mean of 35 Test-pieces from an Unpressed Ingot, and 49 Test-pieces from a Pressed Ingot.			
	Elastic Limit in Tons per Square Inch.	Breaking Tensile-Stress in Tons per Square Inch.	Contraction in Area at Point of Fracture.	Elongation Per Cent. immediately before Fracture.
			Per cent.	
Unpressed ingot, Appendix I .	11·11	29·18	4·41	8·76
Pressed „ „ III .	11·45	29·53	7·90	12·51

COMPARISON of the MEAN RESULTS of the FIVE SERIES of TEST-PIECES CUT DIAMETRICALLY, as per TABLE, APPENDIX VI, from UNFORGED INGOTS.

—	Mean of 35 Test-pieces from an Unpressed Ingot, and 49 Test-pieces from a Pressed Ingot.			
	Elastic Limit in Tons per Square Inch	Breaking-Stress in Tons per Square Inch.	Contraction in Area at Point of Fracture.	Percentage Elongation immediately before Fracture.
			Per cent.	
Unpressed ingot, Appendix II .	11·43	28·64	3·61	7·91
Pressed „ „ IV .	12 38	30·07	7·57	12·74

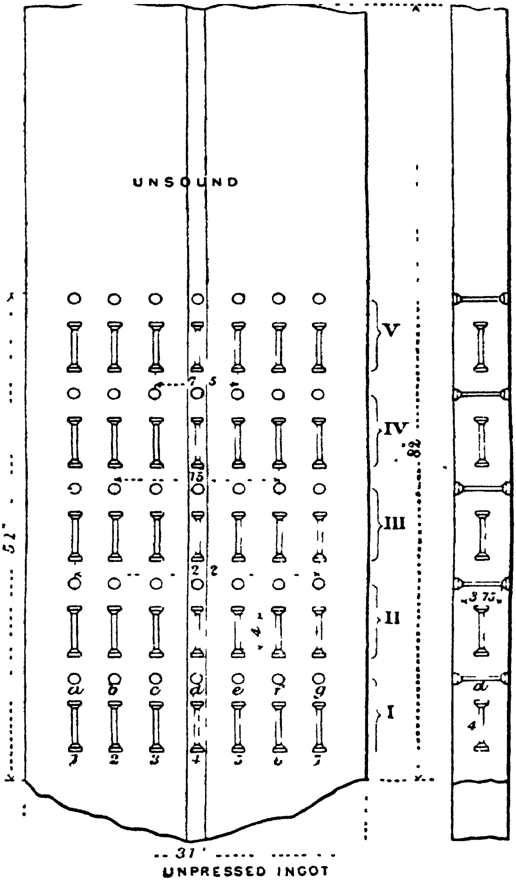
The general preference for forgings of fluid-compressed steel, whenever obtainable, also seems to warrant the conclusion that steel forgings, made from compressed steel, have a somewhat higher tensile-strength and greater ductility than similar forgings from unpressed metal of the same temper; and also that such forgings are more uniform in character and behaviour, and more reliable than forgings from unpressed metal.

COMPARATIVE TESTS MADE UPON PRESSED AND UNPRESSED CAST-INGOTS.

As already noted, important comparative tests were made at the Abouchoff Works, in order to determine the relative merits or demerits of the pressed and unpressed steel ingots, in a manner which individual and isolated tests upon metal which has received treatment in some form or other after it left the ingot moulds fail to indicate, and the Author now proposes to refer to them somewhat in detail.

Description of Tests.—For the purpose of these tests two 500-pood (about 8 tons) ingots were taken, both of open-hearth steel. One 30·75 inches diameter, and 82 inches long, Fig. 1, p. 87, was cast in an open-topped chilled mould in the usual manner; while the other, Fig. 7, p. 116, 34·25 inches in diameter, and 70·2 inches long after fluid-compression, was cast in the mould shown in Figs. 3 and 4, and was submitted to a pressure of 3,937 tons, being 2 tons per inch on the pressing-ram, or 4·34 tons per square inch on the top surface of the ingot. The ingot shortened whilst under the pressure $8\frac{5}{16}$ inches, and it remained under the pressure for three hours and a half. The lower pressure employed in pressing this ingot, as compared with the pressures employed in other cases, as shown in the Table, Appendix IX, arises from the fact that the mould in which this casting was made was originally prepared by the Author for the casting of hollow ingots or hoops, and when used for solid ingots of this diameter was not considered strong enough to safely bear the greater heat of the larger mass of metal, together with the higher pressures known to be necessary to ensure

FIG. 9.



uniformity in an ingot of this size, at every point in the cross-section of the ingot. The two ingots were both made of open-hearth steel, produced from the same materials, pig-iron, steel scrap, spiegeleisen, and ferro-manganese, the scrap being the top ends of unpressed steel ingots. It has been already mentioned, p. 115, how these ingots were divided longitudinally, so as to obtain from the centre of each a slab 4·75 inches in thickness of the full length of the ingots. The unpressed ingot was of a slightly harder temper, was cast a little longer, and was of smaller diameter than the pressed ingot, conditions in favour of the unpressed as compared with the pressed ingot. The two middle slabs from the ingots were then cut up, in the manner shown in

Fig 10

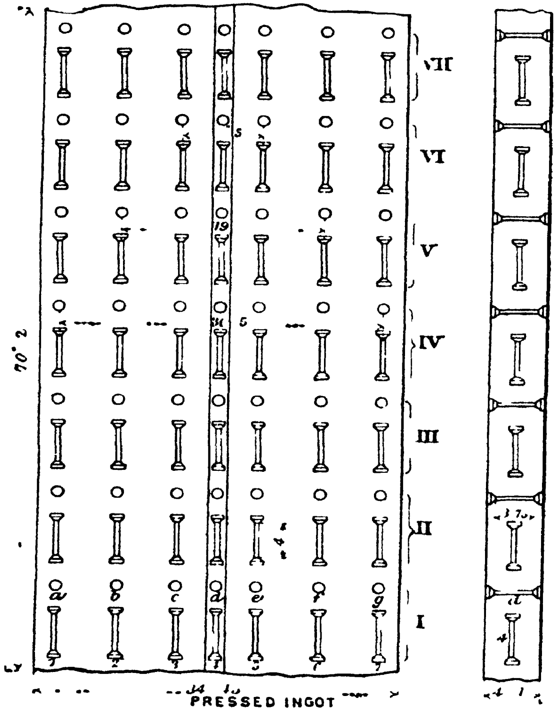


Fig. 9 and Fig. 10, into a series of test-pieces, the series being marked I, II, III, IV, V, in the unpressed ingot (Fig. 9), and I, II, III, IV, V, VI, VII, in the pressed ingot (Fig. 10). Each of these series comprised fourteen tests, of which seven were taken in the direction of the length of the ingot and numbered 1, 2, 3, 4, 5, 6, 7 in each series, while the other seven were taken at right-angles to the former, or across the ingot, and are numbered *a*, *b*, *c*, *d*, *e*, *f*, *g*, in each series. The longitudinal tests numbered

4 in each series were thus intentionally taken directly along the axis, and the test-pieces lettered *d* were cut directly across the axis, the centre of the ingot thus falling at the centre of the length of these test-pieces. The test-pieces were then all broken in a Greenwood and Batley testing-machine, with results to which attention will now be directed.

Besides determining the average tensile-strength, elastic limit, contraction in area before fracture, and ductility of the metal at the several sections of the ingots, the tests were taken in the manner indicated, in order to ascertain what, if any, was the difference in behaviour under applied tensile-stresses of the metal along the axis, and at different radial distances from such vertical axis in the pressed and unpressed ingots respectively. The metal along the vertical axis has been taken, since it is acknowledged to invariably represent, in the pressed ingot, the line of maximum porosity, and of initial stresses due to contraction after the ingot has left the mould. Test-pieces along such a line, when only ½ inch in diameter, must obviously fall in two, without the application of any external stresses, if, as the opponents of fluid-compression aver, this part of the ingots is, and must always be, occupied either by a pipe or series of bubbles.

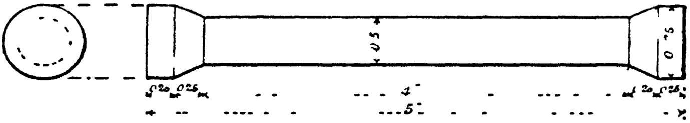
In comparing the averages, as taken at various radial distances (Appendix VIII) from the centre of the ingot, the tests have again been made under the most favourable condition for the unpressed ingot. The latter ingot is not only smaller in diameter, but the seven tests in each series are also taken well inside the surface honey-comb at equal radial distances across the diameter, so as to test only the best metal; while the seven tests across each section of the pressed ingot are not taken equidistant, but Nos. 3 and 5 cut longitudinally, and Nos. *c* and *e*, cut transversely, are each in their respective series nearer to the centre than the average distance between the positions of the several test-pieces, and so to a slight extent tend to lower the mean value for the pressed ingot. Also, it is to be noticed in Series V of Appendix I, as again in Series V of Appendix II, that in the unpressed ingot one test-piece of each series, although taken from a point but little more than half way along the length of the ingot, was still so unsound as to yield no result on testing, and such tests are neglected in the Tables, although throughout the pressed ingot every test-piece from top to bottom is reckoned in the general averages, even though the test-piece may have broken off close to the neck, and so almost invariably have afforded a low result.

No hammering, re-heating, annealing, or treatment of any kind beyond the machine work of planing and turning was performed upon any of the specimens before testing. The test-pieces were all made of the form shown by Fig. 11, turned accurately to ½ inch in diameter, and, as stated in the Tables, were from 3·985 inches to 4·02 inches in length, measured over the parallel part between the shoulders of the specimens marked 1, 2, 3, 4, 5, 6, 7, in each series, and 3·676 inches to 3·747 inches between the shoulders in the specimens marked *a*, *b*, *c*, *d*, *e*, *f*, *g*.

The tests were originally tabulated in atmospheres per square inch, but have been converted into tons per square inch by taking 149·3 atmospheres = 1 ton.

Appendix I and Appendix II give the detailed results of each test in the five series of tests made upon pieces cut longitudinally and transversely respectively, from the unpressed steel ingots of carbon = 0·5 per cent. and manganese = 0·35 per cent.

FIG 11.



Appendixes III and IV detail like results obtained from the seven series of experiments made upon a fluid compressed ingot of carbon = 0·39 per cent.; manganese = 0·4 per cent.

Appendix V shows the average figures for each series of tests in both the compressed and unpressed ingots, and then forms averages for the whole ingots upon the tests cut longitudinally from the ingots. Appendix VI affords the same details with respect to tests made upon the test-pieces cut at right-angles to the length of the ingots.

The first noticeable difference in the series of tests is that, notwithstanding the unpressed ingot was somewhat harder in temper and 82 inches in length, only five series of test-pieces could be obtained from it, and some of these proved faulty; whilst from the compressed ingot, measuring only 70·2 inches in length, the complete seven series of tests were taken, and the whole of the results tabulated. In other words, a length of only 48 inches out of 82 inches of the unpressed ingot was sufficiently sound to permit of approximately good samples being obtained, whilst the full length of the pressed ingot was available for testing purposes. Further, with the pressed ingot, it is permissible to take the test-pieces at any convenient proximity to the skin without fear of unsoundness, whilst, owing to the honey-comb in the circumferential surfaces of the unpressed ingot, only 24 inches out of the 31 inches in diameter were available for testing purposes. The averages tabulated in Appendixes V and VI are thus a comparison of the tests taken from the best or bottom portions only of the unpressed ingot, against the tests made from the whole mass and worst portions of the pressed ingot, including tests made directly along and across the axis of the ingot.

From Appendix V it appears that while the five series of longitudinal tests from the unpressed cast ingot present an average of 11·11 tons per square inch as its limit of elasticity, the pressed cast ingot of milder temper gives an average over the whole seven series, or forty-nine tests, of 11·45 tons. The average breaking-stress is 29·18 tons per square inch in the unpressed, as against 29·53 tons in the fluid-compressed metal; but it is in the amount of extension immediately before fracture that the compressed ingot shows its maximum of superiority. For the two ingots, with practically the same tensile-strength, the stretch before fracture on the average is 8·76 per cent. and 12·51 per cent. of their length in the unpressed and pressed metals respectively, the latter thus exceeding the former by 42·8 per cent. Published results of the tests of gun-material in its cast state are not numerous, but General Maitland has described[1] the casting of an ingot roughly of the shape of a trunnion, from which, after cutting off the top, sufficient metal was left for two trunnions; and on testing these castings before forging, annealing, or otherwise treating them, the average result from the top slice of the metal accepted for the trunnion was 31·9 tons tensile-strength with 5 per cent. elongation in

AVERAGES from APPENDIX V of the LONGITUDINAL TEST-PIECES from UNPRESSED and PRESSED INGOTS, neither FORGED nor ANNEALED.

—	Elastic Limit in Tons per Square Inch.	Breaking Tensile-Stress in Tons per Square Inch.	Contraction in Area at Point of Fracture.	Elongation per cent. in 4 inches immediately before Fracture.
			Per cent.	
Unpressed ingot (35 tests) . .	11·11	29·18	4·41	8·76
Pressed „ (49 tests) . .	11·45	29·53	7·90	12·51

---

[1] Minutes of Proceedings Inst. C.E., vol. lxxxix. p. 131, and Appendix VI.

2 inches, and from the bottom slice 34·42 tons with 8·75 per cent. elongation. These results support the Author's figures as to the low elongation of the unpressed metal, and also of the rapid deterioration from the bottom towards the top of the unpressed ingot.

The test-pieces cut across the ingots (Appendix VI) show still more strongly in favour of fluid-compression. Thus the averages are as under:—

AVERAGE RESULTS from APPENDIX VI of the TRANSVERSE TEST-PIECES from UNPRESSED and PRESSED INGOTS.

— — —	Elastic Limit in Tons per Square Inch	Breaking-Stress in Tons per Square Inch.	Contraction in Area at Point of Fracture.	Percentage Elongation immediately before Fracture.
			Per cent.	
Unpressed ingot	11·43	28·64	3·61	7·91
Pressed „	12·38	30·07	7·57	12·74

These advantages are further accentuated from the consideration of Table VI, which shows that whilst the pressed ingot affords a higher ultimate tensile-strength in the metal of its uppermost sections than it does in its lowest, the unpressed ingot, on the other hand, presents its best results towards the bottom, with a rapid falling-off at points exceeding one-half the length of the ingot. With reference to elongation, the unpressed ingot has a mean (Appendix VI) of 12·44 per cent. at the bottom of the ingot, or series I of the tests, but falls rapidly away throughout series II, III, and IV, until in series V the elongation is only 2·02 per cent. On the other hand, the pressed ingot shows a mean elongation in series I of 13·71 per cent. decreasing somewhat towards the top, yet in series VII, or very top of the ingot, the elongation is still represented by a mean of 11·63 per cent. Examination of Appendix VII and of Appendix VIII shows that in both pressed and unpressed ingots, whether tested by pieces cut longitudinally or across, the maximum value for the elastic limit of the cast metal is reached towards the outer boundaries of the ingot, or in the specimens marked 1, 7, *a* and *g*, in each series, and it tends to decrease in value towards the centre; thus:—

AVERAGE ELASTIC LIMIT at DIFFERENT DISTANCES from CENTRAL AXIS of CAST INGOTS, FIGS. 9 and 10, pp. 121, 122.

——	Mean Value of the Elastic Limit in Tons per Square Inch from Test-pieces.			
	No. 1, No. 7, No. *a* and No. *g*.	No. 2, No. 6, No. *b* and No. *f*.	No. 3, No. 5, No. *c* and No. *e*.	No. 4 and No. *d*, or along and across the Axis.
Unpressed ingot, mean of 5 series	11·75	11·34	10·77	10·98
Pressed ,, ,, 7 ,,	12·14	11·30	11·38	11·90

In like manner, the ultimate breaking-stress appears to follow in order, thus:—

ULTIMATE BREAKING-STRESS at DIFFERENT DISTANCES from the CENTRAL AXIS.

	Mean Value of the Ultimate Breaking-Stress in Tons per Square Inch from Test-pieces.			
	No. 1, No. 7, No. *a* and No. *g*.	No. 2, No. 6, No. *b* and No. *f*.	No. 3, No. 5, No. *c* and No. *e*.	No. 4 and No. *d*, or along and across the Axis.
Unpressed ingot, mean of 5 series	29·60	29·03	27·66	28·13
Pressed ,, ,, 7 ,,	32·48	29·41	28·33	28·13

There is but little difference in the average amount of elongation where the metal is sound in the unpressed ingot, whether tested from near the circumference or from near the axis of the ingot; but the axial or worst portion of the metal from the pressed ingot gives practically the same mean elongation, 8 per cent., as is afforded by the unpressed metal at any section; and the pressed metal shows a marked superiority over the unpressed metal, and rapid increase in ductility as the testing proceeds from the centre, where the ductility is 8 per cent., towards the circumference of the ingot, where it reaches 17·6 per cent.

ELONGATION at DIFFERENT DISTANCES from the CENTRE.

	Mean percentage Elongation immediately before Fracture from Test-pieces.			
	No. 1, No. 7, No. *a* and No *g*.	No. 2, No. 6, No. *b* and No. *f*.	No. 3, No. 5, No. *c* and No. *e*.	No. 4 and No. *d*, or along and across the Axis.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Unpressed ingot, mean of 5 series	7·22	8·22	8·88	8·62
Pressed ,, ,, 7 ,,	17·61	13·15	9·07	8·09

The inference which the Author makes from these last three comparisons is, that wherever the pressure is effective it induces solidity in the ingot, and so raises alike the elastic limit, the ultimate breaking-stress and the ductility of the cast metal, besides increasing its general reliability. It produces ingots, any portion of which (the composition, raw materials, and method of production being always identical for the ingots under comparison), under mechanical tests afford results equal to those obtained from ingots produced by the ordinary methods of casting without pressure, after one-third of such unpressed ingots have been rejected and sent to scrap. Appendix V and Appendix VI show also that the mean of the tests from the top of the pressed ingot (constituting series VI and series VII of the tests, and corresponding to the rejected portion of an unpressed ingot) are equal in elastic limit, ultimate strength, and in ductility, to the mean results obtained in series I and series II made from the bottom or best portions of the unpressed ingot. The figures of Appendixes V and VI further indicate that the weakest part of the pressed ingot is across the central axis, where obviously the pressure must finally be least effective; but even here the mean figures of the pressed and unpressed metals are practically the same, and the pressed metal is at no disadvantage. Hence for ordnance purposes, for tubes, hoops, hollow shafts, &c., where, in the course of their manufacture, the centre of the ingot is removed either in the forge or by boring or turning operations, it becomes unnecessary to proceed to the use of much higher pressures than those which have been employed in the production of the ingot, to which the figures advanced in this Paper refer, and which are the ordinary pressures employed for the fluid compression of such ingots. But were it considered desirable, it is possible, with the press and power available at the Abouchoff Works, to apply and continue such a pressure to an ingot of the size here mentioned, as shall afford a practically sound and homogeneous product, except so far as such results may be modified by the tendency to liquation of the chemical constituents of the steel towards the centre and top of the ingot.

In the ingot under consideration the pressure has obviously been most effective at the circumference; but throughout the mass of metal it has been sufficient to expel practically all liberated gaseous matter, though not quite sufficient to entirely overcome the initial stresses and molecular changes at the centre produced during the cooling of the metal. However, the late General Kalakoutsky, in his investigations upon the internal stresses in metals, has shown that such injurious stresses, although existing in a fluid-compressed ingot, are yet small compared with the similar stresses existing in other castings, or even in large forgings. While thus admitting that any sponginess present in a fluid-compressed ingot will be found along the centre line where its influence is least detrimental, yet, in many instances, no sensible sponginess occurs in any part; and that such does not necessarily occur has often been shown by taking two adjacent samples from the centre of a pressed ingot, from one of which a test-piece is turned and tested direct, while the other is carefully annealed to eliminate initial stresses before the test-piece is prepared. Under these conditions the initial stresses are almost invariably sufficient to ensure low results from the first test-piece, while the annealed sample is always better, and not unfrequently gives results equal to those from any other part of the ingot, which could not be if the original weakness were due to unsoundness alone.

The following experiments made upon the top and bottom disks, cut from the extreme ends of a cast-steel hoop, of 31 inches external and 16 inches internal diameter, and pressed whilst in its fluid state, show, that whilst the elastic limit was not practically affected, the tensile-strength was raised by annealing; but by forging and annealing the samples from the same disks, both the elastic limit and the tensile-strength were raised.

EFFECT of ANNEALING and FORGING upon the EXTREME TOP and BOTTOM DISKS, CUT from a FLUID-COMPRESSED STEEL HOOP of 31 INCHES EXTERNAL DIAMETER and 16 INCHES INTERNAL DIAMETER.

Average of Three Tests.	Elastic Limit in Tons per Square Inch.	Ultimate Tensile-Strength in Tons per Square Inch.
Top disk of pressed hoop, neither forged nor annealed .	19·18	30·36
Bottom disk from pressed hoop, neither forged nor annealed	18·75	32·15
Top disk, annealed but not forged	19·42	36·81
,, forged and annealed	21·43	42·86

Tests from both pressed and unpressed metal after forging, machining, and may-be of tempering and annealing in various fashions, have been published in considerable numbers; but since such tests are influenced to an indefinite extent by the treatment which the metal has received subsequent to the casting stage, it is possible to make almost any desired deductions from them, and the Author has considered it unnecessary, therefore, to burden this Paper with any records of the forged metal beyond the average specimens herewith of the forged steel hoops, as used for various rings in 11-inch breech-loading guns, of an oil-tempered tube, and of a sample of shell-metal.

TEST-PIECES taken from FORGINGS of FLUID-COMPRESSED STEEL.

——	Elastic Limit in Tons per Square Inch.	Ultimate Breaking-Strength in Tons per Square Inch.	Elongation Per Cent. in 4 inches.
Gun-tube forged and annealed	28·53	49·56	18·3
" " " "	29·46	53·58	17·9
" " " "	24·77	46·89	20·2
Hoops for 11-inch breech-loading guns . .	18·75	34·83	17·2
" " " " . .	16·74	30·81	18·9
Gun-tube tempered in oil	27·46	53·57	18·0
Shell-metal in its unhardened state . . .	32·82	61·40	8·9

Reference is directed to one other series of tests upon steel of a harder temper; so far as the Author knows, it is unique, and may therefore be of interest beyond the question of fluid compression. The tests afford evidence of the molecular condition of a successful projectile of fluid-compressed steel after it has been fired at an armour-plate. The shell was made from an ingot of fluid-compressed steel, of 21½ inches diameter weighing 65 cwt. This ingot was first drawn down to 12 inches diameter under the steam-hammer. A piece was then cut from it, and drawn down to ¾-inch square; such piece was afterwards annealed, then turned down into three test-pieces of ½ inch diameter, and tested with the following results:—

——	Length of Test-piece between Shoulders.	Elastic Limit in Tons per Square Inch.	Ultimate Breaking-Stress in Tons per Square Inch.	Percentage Elongation in 5 inches.
Shell-metal in soft state . .	4·97	32·82	58·95	8·0
" " " . .	4·96	32·82	61·42	8·9
" " " . .	4·98	33·49	61·08	7·6

The remainder of the ingot was forged, turned, bored, hardened, &c., for 9-inch shells (25½ inches long), all of which were fired at an iron plate 12 inches in thickness, placed at an angle with the gun. The shell is reported to have penetrated for a length of 20 inches and then rebounded undamaged. Afterwards, one of the shells was with great difficulty cut in the lathe into seven disks, which were numbered consecutively from the nose to the rear. No. 1 was taken across the solid part of the nose, and No. 7 was the extreme rear end of the shell. From each of these disks test-pieces were prepared without any hammering or heating between the firing and the testing, with results hereunder tabulated:—

EXAMINATION of 9-INCH SHELL AFTER the SAME had been FIRED at and had REBOUNDED from the PLATE.

——	Length of Test-piece.	Elastic Limit in Tons per Square Inch.	Ultimate Breaking-Stress in Tons per Square Inch.	Percentage Elongation in the Lengths indicated.
	Inches.			
No. 1, from nose	3·97	66·08	84·46	4·7
„ 2, nearer rear	4·46	56·24	80·37	5·1
„ 3, still nearer rear . . .	4·42	53·57	79·03	5·5
„ 4 „ „ . . .	4·17	52·24	79·03	6·0
„ 5 „ „ . . .	4·45	49·57	77·69	6·8
„ 6 „ „ . . .	4·89	48·22	72·33	7·6
„ 7, at rear	4·90	46·86	71·00	7·6

CONCLUSION.

In conclusion, the Author hopes to be acquitted of any intention of having given greater support to his personal views by the elimination of any unfavourable figures, data, evidence, or phenomena observed during the investigation of this important subject; nothing has been suppressed, so far as he knows, which would help the members in their consideration of the plant or of the process. Throughout the comparisons in the Paper, the intention has been to present the pressed ingot in its less rather than its more favourable aspect, and to give an unbiassed view and expression of opinion upon the process and method for the fluid-compression of steel. Thus, in the two ingots especially dealt with in this Paper, every test-piece of the pressed ingot has been accounted for, and taken into consideration in framing the general averages, although many, if not all, of the more unfavourable figures are attributable to circumstances which might fairly have warranted their elimination. With the unpressed ingot, on the contrary, not only has the upper end corresponding to the series VI and VII of the tests been wholly neglected, but also several test-pieces, even from the five selected series, were found too unsound for further examination, and their existence has been ignored, to the advantage of the quoted general averages. It may be well to state that, contrary to a somewhat prevalent idea, the method of fluid compression described is not a process recommended for ensuring soundness in steel castings of intricate forms; neither, in the form described, is it adapted to the treatment of metal such as is used for rails and other rolled sections, which require to be sold at some £4 or £5 per ton; nor is it proposed as a method to entirely supersede the necessity for forging the metal. But it has its principal application in the production of steel in the ingot form, as required for forgings, wherever the highest and best possible quality for the purpose intended is of paramount importance, but for which a too critical regard to cost is not observed; nevertheless, for many classes of work such as those already cited, and also for railway material, such as cranks, axles, and engine work generally, considering that the whole of the ingot is available, the cost of forgings of fluid-compressed steel need not exceed that of similar forgings produced from ingots cast without fluid-compression.

And lastly, although the Author could not advocate the introduction of unforged steel castings for ordnance, yet he is of opinion that guns may be made at much less cost, thoroughly reliable, and equally as serviceable as the present built-up weapons of the service, from a single ingot of steel, except as to the breech arrangements, and to the trunnion, if such be desired. But he would require that the ingot of steel should be of suitable quality and first be cast under fluid compression, then bored, and afterwards forged upon a mandrel, under a sufficiently powerful hydraulic forging press.

The Paper is illustrated by several drawings and tracings, from which Plate 1 and the Figs. in the text have been engraved.

APPENDIXES.

APPENDIX I.—UNPRESSED INGOT.

Details of tests made upon test-pieces cut parallel with the length of the ingot and marked 1, 2, 3, 4, 5, 6, 7 in each series as per Fig. 9, p. 121. Ingot neither forged nor annealed.

Mark on Test-pieces.	Length of Test-piece between Shoulders.	Elastic Limit in Tons per Square Inch.	Elongation per Inch at Elastic Limit.	Breaking-Stress in Tons per Square Inch.	Elongation immediately before Fracture.	Contraction of Area at Point of Fracture.
	Inches.				Per cent.	Per cent.
Series I. 1	3·990	11·38	0·000850	31·48	12·55	6·62
2	3·970	11·38	0·000850	29·47	16·02	8·83
3	3·989	10·71	0·000800	29·47	16·71	9·63
4	3·995	10·71	0·000800	29·47	17·20	9·45
5	3·982	10·05	0·000750	28·80	14·01	8·63
6	3·967	11·38	0·000850	30·14	15·52	9·45
7	3·977	13·39	0·001000	31·48	11·84	6·62
Average	3·981	11·28	0·000842	30·04	14·83	8·46
Series II. 1	3·993	12·05	0·000900	30·81	8·56	4·21
2	3·995	11·38	0·000850	29·47	12·76	5·62
3	4·005	11·38	0·000850	29·47	11·98	6·02
4	3·994	10·71	0·000800	28·13	11·54	7·02
5	3·990	10·71	0·000800	29·47	12·25	5·62
6	3·985	11·38	0·000850	30·81	12·89	5·82
7	4·006	12·05	0·000900	29·47	6·54	2·40
Average	3·995	11·38	0·000850	29·66	10·93	5·24
Series III. 1	3·977	12·05	0·000900	29·47	7·73	3·41
2	3·977	11·38	0·000850	30·14	7·05	4·01
3	3·985	12·05	0·000900	30·14	12·56	7·42
4	3·980	10·71	0·000800	28·80	10·16	5·42
5	3·993	10·71	0·000800	29·47	11·75	5·02
6	3·985	11·38	0·000850	28·13	6·82	2·21
7	3·993	10·71	0·000800	29·47	6·05	3·82
Average	3·984	11·25	0·000842	29·37	8·87	4·47
Series IV. 1	4·016	11·38	0·000850	27·46	4·53	1·40
2	3·980	10·71	0·000800	28·13	6·25	3·80
3	3·972	10·71	0·000800	28·13	5·11	2·60
4	3·986	10·71	0·000800	28·13	4·18	1·80
5	3·986	10·05	0·000750	26·79	3·31	1·40
6	3·995	10·71	0·000800	28·13	5·65	2·20
7	3·988	10·71	0·000800	28·80	9·50	2·00
Average	3·989	10·71	0·000800	27·94	5·50	2·31
Series V. 1	3·993	11·38	0·000850	28·80	3·28	1·20
2	3·997	10·05	0·000750	26·79	2·52	0·60
3	3·983	10·71	0·000800	29·47	3·66	1·42
4	3·968	10·71	0·000800	25·45	1·75	0·20
5	3·986	11·38	0·000850	30·81	3·91	1·60
6	Test-piece unsound, full of holes; no result obtainable.					
7	3·981	11·38	0·000850	32·15	6·80	3·21
Average	3·984	10·93	0·000816	28·91	3·65	1·37

APPENDIX II.—UNPRESSED INGOT.

Details of tests made upon test-pieces cut transversely, or at right-angles to those of Appendix I and marked *a*, *b*, *c*, *d*, *e*, *f*, *g* in each series as per Fig. 9, p. 121. Ingot neither forged nor annealed.

Mark on Test-piece.		Length of Test-piece between Shoulders.	Elastic Limit in Tons per Square Inch.	Elongation per Inch at Elastic Limit	Breaking-Stress in Tons per Square Inch.	Elongation immediately before Fracture.	Contraction of Area at Point of Fracture.
		Inches.				Per cent.	Per cent.
Series I.	*a*	3·716	12·05	0·000900	29·47	8·47	4·60
	b	3·707	12·05	0·000900	30·14	10·46	8·47
	c	3·724	10·71	0·000800	29·47	12·40	5·62
	d	3·716	12·05	0·000900	29·47	14·88	8·03
	e	3·714	11·38	0·000850	29·47	14·56	7·63
	f	3·729	12·05	0·000900	29·47	15·34	6·82
	g	3·711	12·05	0·000900	29·47	11·02	4·80
Average		3·716	11·76	0·000878	29·57	12·44	6·56
Series II.	*a*	3·729	11·38	0·000850	29·47	5·89	2·61
	b	3·723	12·05	0·000900	30·14	10·93	5·22
	c	3·741	10·05	0·000750	29·47	12·64	6·42
	d	3·734	10·71	0·000800	28·80	11·51	5·82
	e	3·722	10·71	0·000800	28·13	8·86	4·61
	f	3·738	11·38	0·000850	30·14	13·96	6·42
	g	3·736	12·05	0·000900	30·14	6·74	3·01
Average		3·771	11·19	0·000835	29·47	10·07	4·87
Series III.	*a*	3·751	12·05	0·000900	31·48	7·73	3·81
	b	3·756	12·05	0·000900	30·81	7·05	2·81
	c	3·740	11·38	0·000850	30·81	12·56	6·42
	d	3·757	11·38	0·000850	30·81	10·16	5·[illegible]
	e	3·759	12·05	0·000900	31·4[illegible]	11·75	7·02
	f	3·751	12·05	0·000900	30·81	6·8[illegible]	2·20
	g	3·749	11·38	0·000850	30·14	6·05	3·21
Average		3·751	11·76	0·000878	30·91	8·87	4·35
Series IV.	*a*	3·737	12·05	0·000900	30·81	8·56	1·40
	b	3·727	11·38	0·000850	28·13	2·17	0·60
	c	3·734	12·05	0·000900	30·81	4·79	2·40
	d	3·731	10·71	0·000800	26·78	2·49	0·80
	e	3·738	11·38	0·000850	31·48	4·36	2·00
	f	3·725	11·38	0·000850	32·15	7·24	1·60
	g	3·744	11·38	0·000850	32·15	6·62	3·61
Average		3·733	11·47	0·000857	30·33	5·17	1·74
Series V.	*a*						
	b	3·734	10·71	0·000800	22·77	2·11	0·40
	c	3·728	8·70	0·000650	10·05	0·26	0·20
	d	3·748	11·38	0·000850	25·45	2·37	0·60
	e	Test-piece full of holes, and no result obtainable.					
	f	3·748	12·05	0·000900	28·13	2·32	0·80
	g	3·727	12·05	0·000900	28·13	3·03	0·60
Average		3·733	10·98	0·000820	22·91	2·02	0·52

APPENDIX III.—FLUID-COMPRESSED INGOT.

Details of tests made upon test-pieces cut parallel with the length of the ingot and marked 1, 2, 3, 4, 5, 6, 7 in each series as per Fig. 10, p. 122. Ingot neither forged nor annealed.

	Mark on Test-piece.	Length of Test-piece between Shoulders.	Elastic Limit in Tons per Square Inch.	Elongation per Inch at Elastic Limit.	Breaking-Stress in Tons per Square Inch.	Elongation immediately before Fracture.	Contraction of Area at Point of Fracture.
		Inches.				Per cent.	Per cent.
Series I.	1	3·993	10·71	0·000800	30·14	22·81	14·85
	2	3·998	10·05	0·000750	27·46	18·71	22·69
	3	4·011	10·71	0·000800	24·11	7·87	5·02
	4	4·005	10·05	0·000750	24·78	8·41	6·62
	5	3·996	10·71	0·000800	26·79	13·56	7·63
	6	4·007	10·05	0·000750	28·13	27·60	25·10
	7	3·986	10·71	0·000800	30·14	22·07	18·27
Average		3·999	10·43	0·000778	27·36	17·29	14·45
Series II.	1	4·019	12·05	0·000900	33·49	15·65	8·40
	2	3·999	10·71	0·000800	29·47	23·35	16·06
	3	4·005	9·37	0·000700	27·46	17·37	8·83
	4	3·994	9·37	0·000700	24·78	9·83	7·02
	5	3·993	9·37	0·000700	27·46	13·87	9·09
	6	3·997	10·05	0·000750	28·13	18·53	13·42
	7	3·990	12·05	0·000900	33·49	16·46	10·04
Average		3·999	10·42	0·000778	29·18	17·43	10·55
Series III.	1	4·020	12·73	0·000950	32·82	14·77	11·24
	2	4·004	10·71	0·000800	28·80	15·98	10·64
	3	3·999	10·05	0·000750	28·13	10·82	5·22
	4	3·990	10·05	0·000750	29·47	11·52	6·02
	5	3·993	10·71	0·000800	28·80	10·96	5·22
	6	3·996	11·38	0·000850	28·80	18·84	17·50
	7	3·983	12·73	0·000950	32·82	16·26	12·85
Average		3·997	11·19	0·000835	29·95	14·16	9·81

APPENDIX III (FLUID-COMPRESSED INGOT)—*continued.*

Mark on Test-piece.	Length of Test-piece between Shoulders.	Elastic Limit in Tons per Square Inch.	Elongation per Inch at Elastic Limit.	Breaking-Stress in Tons per Square Inch.	Elongation immediately before Fracture.	Contraction of Area at Point of Fracture.
	Inches.				Per cent.	Per cent.
Series IV. 1	3·983	12·73	0·000950	32·15	15·81	8·85
2	3·987	12·05	0·000900	28·80	6·01	1·60
3	4·000	11·38	0·000850	27·46	5·25	2·40
4	3·981	11·38	0·000850	27·46	5·50	2·40
5	3·980	11·38	0·000850	26·12	4·29	1·81
6	3·972	12·05	0·000900	27·46	5·03	3·01
7	3·982	12·73	0·000950	32·82	17·35	10·66
Average	3·983	11·96	0·000892	28·89	8·46	4·39
Series V. 1	3·994	12·05	0·000900	32·15	17·80	12·22
2	3·989	12·05	0·000900	26·12	5·71	2·40
3	3·989	12·73	0·000950	26·12	4·28	2·20
4	4·023	11·38	0·000850	28·13	5·46	2·81
5	3·987	12·05	0·000900	26·12	4·26	2·61
6	3·997	12·05	0·000900	30·14	8·20	3·21
7	4·000	10·71	0·000800	32·15	15·60	9·63
Average	3·997	11·86	0·000885	28·70	8·67	5·01
Series VI. 1	4·003	12·73	0·000950	32·15	17·58	7·63
2	3·990	12·05	0·000900	31·48	11·42	7·44
3	3·994	12·05	0·000900	25·45	2·85	1·20[1]
4	3·990	12·05	0·000900	30·81	4·03	1·40[2]
5	3·992	12·73	0·000950	25·45	2·80	1·00[3]
6	3·973	11·38	0·000850	30·81	8·83	3·21
7	4·003	12·73	0·000950	33·49	17·74	10·10
Average	3·992	12·24	0·000914	29·95	9·32	4·57
Series VII. 1	3·980	12·73	0·000950	33·49	16·98	10·24
2	4·012	12·05	0·000900	32·82	12·38	5·63
3	4·004	12·05	0·000900	32·15	8·39	3·82
4	4·006	12·05	0·000900	31·48	6·76	3·23
5	4·005	12·05	0·000900	32·82	10·03	5·82
6	3·985	11·38	0·000850	32·82	13·55	8·43
7	4·004	12·05	0·000900	32·82	17·43	8·63
Average	3·999	12·05	0·000900	32·63	12·21	6·54

[1] Unsound at fracture. [2] Broke in neck. [3] Unsound at fracture.

APPENDIX IV.—FLUID-COMPRESSED INGOT.

Details of tests made upon test-pieces cut in a plane at right angles to length of ingot, and marked *a*, *b*, *c*, *d*, *e*, *f*, *g* in each series as per Fig. 10, p. 122. Ingot neither forged nor annealed.

Mark on Test-piece.	Length of Test-piece between Shoulders.	Elastic Limit in Tons per Square Inch.	Elongation per Inch at Elastic Limit.	Breaking-Stress in Tons per Square Inch.	Elongation immediately before Fracture.	Contraction of Area at Point of Fracture.
	Inches.				Per cent.	Per cent.
Series I. *a*	3·737	12·05	0·000900	32·82	16·83	11·86
b	3·721	8·70	0·000650	26·12	11·85	5·44
c	3·670	10·71	0·000800	27·46	12·53	7·41
d	3·743	9·37	0·000700	15·40	2·67	1·60
e	3·721	8·70	0·000650	27·46	20·69	15·86
f	3·722	8·70	0·000650	27·46	13·48	7·22
g	3·726	9·37	0·000700	32·15	17·95	10·24
Average	3·720	9·66	0·000706	26·98	13·71	8·51
Series II. *a*	3·734	12·73	0·000900	33·49	16·92	11·04
b	3·666	10·71	0·000800	29·47	19·17	9·43
c	3·741	10·05	0·000750	28·80	15·12	10·40
d	3·728	9·37	0·000700	28·80	16·20	10·24
e	3·739	10·71	0·000800	29·47	16·42	10·04
f	3·748	10·71	0·000800	29·47	16·96	11·84
g	3·744	12·73	0·000950	33·49	15·11	5·82
Average	3·728	11·00	0·000821	30·43	16·55	9·94
Series III. *a*	3·738	13·39	0·001000	32·82	16·74	11·04
b	3·676	11·38	0·000850	30·81	17·11	10·24
c	3·739	11·38	0·000850	30·14	9·17	3·81
d	3·742	10·71	0·000800	28·13	6·42	3·61
e	3·743	11·38	0·000850	30·14	10·23	6·02
f	3·747	11·38	0·000850	29·47	8·70	3·80
g	3·721	12·73	0·000950	32·15	18·46	10·84
Average	3·729	11·76	0·000878	30·52	12·40	7·05

APPENDIX IV (FLUID-COMPRESSED INGOT)—*continued.*

Mark on Test-Piece.	Length of Test-piece between Shoulders.	Elastic Limit in Tons per Square Inch.	Elongation per Inch at Elastic Limit.	Breaking-Stress in Tons per Square Inch.	Elongation immediately before Fracture.	Contraction of Area at Point of Fracture.
	Inches.				Per cent.	Per cent.
Series IV. *a*	3·714	12·73	0·000950	32·15	16·79	9·60
b	3·641	12·05	0·000900	31·48	10·49	4·40
c	3·742	12·05	0·000900	31·48	9·70	4·00
d	3·737	11·38	0·000850	31·48	13·83	6·61
e	3·728	12·05	0·000900	31·48	8·71	4·41
f	3·736	12·05	0·000900	30·81	9·20	4·40
g	3·726	12·73	0·000950	32·82	21·09	12·60
Average	3·717	12·16	0·000907	31·67	12·83	6·57
Series V. *a*	3·735	12·73	0·000950	32·15	16·43	13·02
b	3·675	12·05	0·000900	28·13	6·20	2·20
c	3·742	12·05	0·000900	27·46	3·82	1·60
d	3·742	12·73	0·000950	28·80	5·18	2·20
e	3·743	12·73	0·000950	30·81	6·89	3·40
f	3·734	12·05	0·000900	31·48	14·21	9·01
g	3·744	11·38	0·000850	32·82	18·24	10·42
Average	3·730	12·25	0·000914	30·24	10·13	5·97
Series VI. *a*	3·733	12·73	0·000950	32·82	21·80	6·03
b	3·679	12·05	0·000900	32·82	16·39	11·84
c	3·725	12·05	0·000900	30·14	4·91	1·80
d	3·716	17·41	0·001300	34·83	5·05	3·01
e	3·740	14·73	0·001100	32·15	5·00	2·20
f	3·731	12·05	0·000900	32·82	15·92	9·63
g	3·722	13·39	0·001000	32·82	14·34	8·83
Average	3·720	13·49	0·001007	32·63	11·91	5·33
Series VII. *a*	3·718	12·73	0·000950	33·49	17·85	16·89
b	3·712	12·05	0·000900	23·44	2·80	1·61[1]
c	3·752	11·38	0·000850	22·77	3·25	1·01
d	3·751	11·38	0·000850	29·47	12·34	10·08
e	3·736	11·38	0·000850	29·47	11·64	5·62
f	3·755	10·71	0·000800	28·13	12·49	7·84
g	3·745	10·71	0·000800	29·47	21·09	24·29
Average	3·738	11·48	0·000857	28·03	11·63	9·62

[1] Broke in neck.

APPENDIX V.

Summary of the average results obtained from *test-pieces cut parallel with the length of the ingot* and numbered 1, 2, 3, 4, 5, 6, 7 for unpressed and fluid-compressed ingots, Appendixes I and III. Ingots neither forged nor annealed.

—	UNPRESSED INGOT (Carbon 0·50 per cent)				PRESSED INGOT (Carbon 0·39 per cent.).			
	Elastic Limit in Tons per Square Inch.	Breaking-Stress in Tons per Square Inch.	Elongation immediately before Fracture	Contraction in Area at Point of Fracture.	Elastic Limit in Tons per Square Inch	Breaking-Stress in Tons per Square Inch.	Elongation immediately before Fracture	Contraction in Area at Point of Fracture.
			Per Cent	Per Cent			Per Cent.	Per Cent.
Averages of Series I .	11·28	30·04	14·83	8·46	10·43	27·36	17·29	14·45
" " II .	11·38	29·66	10·93	5·24	10·42	29·18	17·43	10·55
" " III .	11·25	29·37	8·87	4·47	11·19	29·95	14·16	9·81
" " IV .	10·71	27·94	5·50	2·31	11·96	28·89	8·46	4·39
" " V .	10·93	28·91	3·65	1·37	11·86	28·70	8·67	5·01
" " VI .	Top end of ingot unsound and rejected.				12·24	29·95	9·32	4·56
" " VII .					12·05	32·63	12·21	6·54
Average . . .	11·11	29·18	8·76	4·41	11·45	29·53	12·51	7·90

APPENDIX VI.

Summary of the average results obtained from *test-pieces cut in a plane at right-angles to the length of the ingot* and figured *a, b, c, d, e, f, g,* Figs. 9 and 10, pp. 121, 122, for unpressed and fluid-compressed ingots, Appendixes II and IV. Ingots neither forged nor annealed.

—	UNPRESSED INGOT (Carbon 0·50 per cent.).				PRESSED INGOT (Carbon 0.39 per cent).			
	Elastic Limit in Tons per Square Inch.	Breaking-Stress in Tons per Square Inch.	Elongation immediately before Fracture	Contraction in Area at Point of Fracture.	Elastic Limit in Tons per Square Inch.	Breaking-Stress in Tons per Square Inch.	Elongation immediately before Fracture.	Contraction in Area at Point of Fracture.
			Per Cent.	Per Cent.			Per Cent.	Per Cent.
Averages of Series I.	11·76	29·57	12·44	6·56	9·66	26·98	13·71	8·51
" " II.	11·19	29·47	10·07	4·87	11·00	30·43	16·55	9·94
" " III.	11·76	30·91	8·87	4·35	11·76	30·52	12·40	7·05
" " IV.	11·47	30·33	5·17	1·74	12·16	31·67	12·83	6·57
" " V.	10·98	22·91	2·02	0·52	12·25	30·24	10·13	5·97
" " VI.	Top end of ingot unsound and rejected.				13·49	32·63	11·91	5·33
" " VII.					11·48	28·03	11·63	9·62
Average . .	11·43	28·64	7·91	3·61	12·38	30·07	12·74	7·57

Appendix VII.

Mean results obtained from the test series cut longitudinally and at increasing distances from the centre, of the unpressed and fluid-compressed ingots respectively, compared as to elastic limit, breaking stress, percentage of elongation before fracture and contraction of area at point of fracture. Ingots neither forged nor annealed.

Position along Ingot in Figs	Elastic Limit in							
	Unpressed Ingot, Fig 9, p 121				Fluid-Compressed Ingot, Fig. 10, p. 122.			
	Mean Value in Tons per Square Inch of Section.				Mean Value in Tons per Square Inch of Section.			
	Test-pieces No. 1 and No 7	Test-pieces No 2 and No 6.	Test-pieces No 3 and No. 5.	Test-pieces along Axis of Ingot.	Test-pieces No 1 and No 7.	Test-pieces No 2 and No 6.	Test-pieces No 3 and No 5.	Test-pieces along Axis.
Series I	12·38	11·38	10·38	10·71	10·71	10·05	10·71	10·05
" II	12·05	11·38	11·04	10·71	12·05	10·38	9·37	9·37
" III	11·38	11·38	11·38	10·71	12·73	11·04	10·38	10·05
" IV	11·04	10·71	10·38	10·71	12·73	12·05	11·38	11·38
" V	11·38	10·05	11·04	10·71	11·38	12·05	12·38	11·38
" VI . . . . . }		Unsound and not tested			12·73	11·71	12·38	12·05
" VII . . . . . }					12·39	11·71	12·05	12·05
Mean value of the series	11·65	10·98	10·84	10·71	12·09	11·28	11·24	10·90
	Breaking-Stress							
Series I	31·48	29·80	29·13	29·47	30·14	27·79	25·45	24·78
" II	30·14	30·14	29·47	28·13	33·49	28·80	27·46	24·78
" III	29·47	29·13	29·80	28·80	32·82	28·80	28·46	29·47
" IV	28·13	28·13	27·46	28·13	32·48	28·13	26·79	27·46
" V	30·13	26·79	30·14	25·45	32·15	28·13	26·12	28·13
" VI . . . . . }		Unsound and not tested.			32·82	31·44	25·45	30·81
" VII . . . . . }					33·15	32·82	32·48	31·48
Mean value	29·87	28·80	29·20	28·00	32·44	29·40	27·46	28·13

Appendix VII—*continued.*

AVERAGE PERCENTAGE of ELONGATION IMMEDIATELY BEFORE FRACTURE.								
	ELASTIC LIMIT IN							
	UNPRESSED INGOT, Fig. 9, p. 121.				FLUID-COMPRESSED INGOT, Fig. 10, p. 122.			
Position along Ingots in Figs.	Mean Value in Tons per Square Inch of Section.				Mean Value in Tons per Square Inch of Section.			
	Test-pieces No. 1 and No. 7.	Test pieces No 2 and No. 6.	Test-pieces No. 3 and No. 5.	Test-pieces along Axis of Ingot.	Test-pieces No. 1 and No. 7.	Test-pieces No 2 and No. 6.	Test-pieces No. 3 and No. 5.	Test-pieces along Axis.
Series I	12·17	15·77	15·36	17·20	22·44	23·15	10·71	8·41
" II	7·55	12·82	12·11	11·54	16·05	20·94	15·62	9·83
" III	6·89	6·98	12·15	10·16	15·51	17·41	10·89	11·52
" IV	7·01	5·95	4·21	4·18	16·58	5·52	4·77	5·50
" V	5·00	2·52	3·78	1·75	16·70	6·95	4·27	5·46
" VI	Too unsound to test				17·66	10·12	2·83	4·03
" VII					17·75	12·96	9·21	6·76
Mean value	7·74	8·81	9·52	8·97	17·53	13·86	8·33	7·36
MEAN PERCENTAGE of CONTRACTION in AREA at POINT of FRACTURE.								
Series I	6·62	9·14	9·13	9·45	16·56	23·89	6·33	6·62
" II	3·30	5·72	5·82	7·02	9·22	14·74	8·96	7·02
" III	3·61	3·11	6·22	5·42	12·05	14·07	5·22	6·02
" IV	1·70	3·00	2·00	1·80	9·75	2·32	2·10	2·40
" V	2·20	0·60	1·51	0·20	10·93	2·80	2·41	2·81
" VI	Unsound				8·87	5·32	1·20	1·40
" VII					9·44	7·13	4·82	3·23
Mean value	3·49	3·08	4·94	4·78	9·55	10·04	4·44	4·21

Appendix VIII.

Mean results obtained from the test-pieces cut transversely and at increasing distances from the centre of the unpressed and fluid-compressed ingots respectively, compared as to elastic limit, breaking-stress, percentage of elongation before fracture, and contraction of area at point of fracture. Ingots neither forged nor annealed.

	Elastic Limit in							
Position along Axis in Figs. 9 and 10.	Unpressed Ingot, Fig. 9, p. 121.				Pressed Ingot, Fig. 10, p. 122.			
	Mean Value in Tons per Square Inch of Section.				Mean Value in Tons per Square Inch of Section.			
	Test-Pieces No. *a* and No. *g*.	Test-Pieces No *b* and No. *f*.	Test-Pieces No. *c* and No. *e*.	Test-Pieces across Axis of Ingot.	Test-Pieces No. *a* and No. *g*.	Test-Pieces No. *b* and No. *f*.	Test-Pieces No. *c* and No. *e*.	Test-Pieces across Axis of Ingot.
Series I.	12·05	12·05	11·04	12·05	10·71	8·70	9·70	9·37
,, II.	11·71	11·71	10·38	10·71	12·73	10·71	10·38	9·37
,, III.	11·71	12·05	11·71	11·38	13·06	11·38	11·38	10·71
,, IV.	11·71	11·38	11·71	11·71	12·73	12·05	12·05	11·38
,, V.	12·05	11·38	8·70	11·38	12·05	12·05	12·39	12·73
,, VI.	..	..	..	..	13·06	12·05	13·39	17·41
,, VII.	..	..	..	..	11·72	11·38	11·38	11·38
Mean value of the Series	11·85	11·71	10·71	11·25	12·29	11·33	11·52	11·76
Breaking-Stress.								
Series I.	29·47	29·80	29·47	29·47	32·48	26·79	27·46	15·40
,, II.	29·80	30·14	28·80	28·80	33·49	29·47	29·13	28·80
,, III.	30·81	30·81	31·14	30·81	32·48	30·14	30·14	28·13
,, IV.	31·48	30·14	31·14	26·78	32·48	31·14	31·48	31·48
,, V.	28·13	25·45	10·05	25·45	32·48	29·80	29·13	28·80
,, VI.	..	..	..	..	32·82	32·82	31·14	34·83
,, VII.	..	..	..	..	31·48	25·79	26·12	29·47
Mean value	29·34	29·37	26·12	28·26	32·53	29·42	29·27	28·13
Average percentage of ELONGATION immediately before fracture.								
Series I	9·74	12·90	13·48	14·88	17·39	12·66	16·11	2·67
,, II	6·31	12·44	10·75	11·51	16·01	18·06	15·77	16·20
,, III.	6·89	6·93	12·15	10·16	17·60	12·90	9·70	6·42
,, IV.	7·59	4·70	4·57	2·49	18·94	9·84	9·20	13·83
,, V.	3·03	1·21	0·26	2·37	17·33	10·20	5·35	5·18
,, VI.	..	..	..	..	18·07	16·16	4·95	5·05
,, VII.	..	..	..	..	19·47	7·25	7·45	12·34
Mean value	6·71	7·64	8·24	8·28	17·70	12·44	9·80	8·81
Mean percentage of CONTRACTION in AREA at point of fracture.								
Series I.	4·70	7·65	6·63	8·03	11·05	6·33	11·63	1·60
,, II.	2·81	5·82	5·51	5·82	8·43	10·63	10·22	0·24
,, III.	3·51	2·50	6·71	5·03	10·91	7·02	4·91	13·61
,, IV	2·50	1·10	2·20	0·80	10·80	4·40	4·20	6·61
,, V.	0·60	0·60	0·20	0·60	11·72	5·60	2·50	2·20
,, VI.	..	..	..	..	7·43	10·73	2·00	3·01
,, VII.	..	..	..	..	20·59	4·72	3·31	10·08
Mean value	2·82	3·53	4·25	4·056	11·57	7·06	5·54	5·34

APPENDIX IX.—DETAILS of the CONDUCT of the FLUID COMPRESSION of STEEL INGOTS and HOOPS.

No.	Metal.	Size of Ingot.	Pressure on Gauge per Square Inch.	Time during which the Pressure acted.	Gross Pressure on the ends of the Ingot.	Pressure per Square Inch on Upper Surface of the Ingot.	Gross Capacity of the Press.	Made in Press.	Remarks.
		Inches diameter.	Tons.	Minutes.	Tons.	Tons.	Tons.		
1	Crucible .	9	0·3	10	212·0	3·33	2,000	Fig. 8	
2	" .	15	1·0	30	1,963·5	11·11	10,000	" 12	Ingot was cut into halves, and showed a very small pipe along the centre.
3	" .	15	1·0	33	1,963·5	11·11	10.000	" "	Ingot was parted, and was perfectly sound.
4	" .	15	1·0	36	1,963·5	11·11	10,000	" "	Ingot parted across middle, no pipe or cracks visible, but two small holes near the centre.
5	" .	15	1·0	37	1,963·5	11·11	10,000	" "	Do. do.
6	" .	15	1·25	42	2,454·37	13·88	10,000	" "	Parted and found perfectly sound.
7	Open-hearth	15	0·875	50	1,718·10	9·72	10,000	" "	Do. do.
8	Crucible .	15	0·875	47	1,718·10	9·72	10,000	" "	Parted into three pieces, and appeared quite sound.
9	" .	17	1·50	30	1,060·20	4·67	2,000	" 8	
10	" .	21	2·00	30	1,413·60	4·08	2,000	" "	
11	" .	21	2·125	70	2,209·00	6·38	10,000	" 10	Parted in five sections, and each quite sound.
12	" .	21	2·125	70	2,209·00	6·38	10,000	" "	Do. do.
13	" .	21	2·125	75	2,209·00	6·38	10,000	" "	Do. do.
14	" .	28	1·00	40	2,595·00	4·21	8,000	" 9	
15	" .	32	1·50	45	3,893·20	4·84	8,000	" "	
16	Open-hearth	34	2·00	Hours. 3½	3,927·00	4·33	10,000	" 10	Sound, as per Fig. 7, p. 116, and photograph, but weak along centre, owing to small pressure employed.
17	Crucible .	Hoop 31-inch external and 16-inch internal dia.	4·00	Minutes. 40	7,854·00	14·16	10,000	" "	Parted into rings, and all perfectly sound.
18	" .	Do.	2·00	38	3,937·00	7·11	10,000	" "	Do. do.
19	" .	Do.	2·00	41½	3,937·00	7·11	10,000	" "	Do. do.
20	Open-hearth	Do.	1·50	48	2,945·30	5·32	10,000	" "	
21	Crucible .	Hoop 36½-in dia. with 19-in. core	2·25	51	4,417·90	5·80	10,000	" "	Do. do.
22	Open-hearth	Do.	2·00	54	3,927·00	5·15	10,000	" "	Do. do.

Discussion.

Mr. Ellis.

Mr. J. D. Ellis said the Paper required a great deal of consideration, for when looked at it really amounted to this, that not only in England, but in the world, only two steel-makers were making steel upon the proper system. He thought that would hardly be admitted. Considering the splendid steel which had been produced for some years by English and foreign makers—such makers as Messrs. Vickers, Messrs. Firths, Messrs. Cammell, and others in Sheffield, Messrs. Krupp, the Creusot Company, and others on the Continent, it could hardly be supposed that their working had been altogether wrong for so many years. No doubt the Author believed everything he had said to be absolutely correct, but there were several statements in the Paper which, as far as his own experience went, were not correct. The first complaint he had to make of the Paper was with regard to Fig. 2. If that represented anything like the ingots of which the steel-makers of England were making steel, the sooner they gave way to others who would make a more reliable material the better. But he contended that that did not represent the ingots that were being used in the trade. The Author had said that it was necessary to cut off one-third of the ingots made unless they were compressed. With that he entirely agreed, but he did not admit that this was altogether an evil. Those who had been in the habit of making large ingots were aware that if the metal was kept hot enough for a sufficiently long time, the various impurities, always to be found in steel, would gradually come to the top; and when the top third of the ingot was cut off, the two-thirds remaining were really better than the original mass of the ingot. He was speaking of the ingots of steel, not poured into iron moulds, but into sand or other material. The samples exhibited, he presumed, had been poured into iron moulds, and that fact accounted for their unsoundness on the edge, referred to by the Author. But large ingots that had been poured into moulds made of composition did not show that inequality, or any appreciable objectionable portions. During the past few years he had cut through many ingots, and he was prepared to state that when the top third of an ingot was cut off, the other portion was absolutely sound, and there was not one ingot in twenty that had a speck in it as large as a pea. He was therefore justified in saying that Fig. 2 did not represent the kind of ingot that steel-makers who were really making good steel

Mr. Ellis. were at present producing. The Author had stated, "The shortening in the length of the ingots, measured between the lengths when fluid, and on removal of the ingots from the mould after pressing, usually amounts to 1½ inch per foot of length." He had measured ingots year after year, say 4 feet in diameter and 12 feet in length, that without any pressure would sink at least 1 inch in the foot; that showed that the steel itself must be exceedingly solid even without the pressure given by the Whitworth press. He had seen Sir Joseph Whitworth some years ago on the subject, and Sir Joseph had told him that he had not then brought the matter to perfection, but that when he had, he should be happy to speak to steel manufacturers with a view to their taking licenses. But from that time to his death he had never heard anything from him on the subject; he therefore presumed that he had never made up his mind to carry it out. The Author had further stated, "The freedom of rolled and hammered bars from roaks and seams is for special applications of exceeding importance; and it is within the Author's knowledge, that to ensure this with ordinary ingots, as much as 30 per cent. of the metal has been turned away from the surface of the ingots, in order to remove the surface honey-comb before commencing to hammer or roll the metal; whilst the same orders have been fulfilled with equally clean bars from fluid compressed metal without the preliminary loss in material, labour and time, involved in turning down the ingots." He could only say that that was not his experience; he did not find that roaky exterior existed in the ingots at present being made. With reference to the concluding part of the Paper, which referred to armour-plates, he observed that the Author had taken notes of the tests against iron armour-plates, but for some years past all the tests of steel shot had been made against either steel or steel-faced plates, so that he could not draw any comparison from them.

Mr. Parker. Mr. WILLIAM PARKER remarked that seven or eight years ago he had met Sir Joseph Whitworth on a visit to his works at Openshaw, and he was highly gratified to see the magnificent plant and the excellent material that was being turned out. He considered that it was really the correct material for the purpose for which it was being manufactured, more especially for marine-engine shafts, in which he was more particularly interested. The question as to what was the proper material for these shafts was one of very great moment to marine engineers and shipowners. He had recently received a circular issued by the International Underwriters' Association of Berlin, which had been confirmed by the underwriters of this country, in which

Mr. Parker.

it was stated that of the losses they had to pay, and the claims made upon them, from 28 to 29 per cent. were for broken shafts. He was sure that if a material could be produced that would reduce that great percentage of accidents, it would be a great boon to the ship-owning community in regard to the saving both of life and of property. Considering the number of large Atlantic steamers sailing between England and America with shafts of quite 30 feet in length and 26 inches in diameter, and the number of lives and the quantity of property on board, every one would agree that the proper material for these shafts was one of the most important considerations in connection with the manufacture of steel. On the occasion of his visit to the works at Openshaw, Sir Joseph Whitworth (than whom, in his opinion, no greater mechanician then lived) informed him that in order to obtain a thoroughly homogeneous sound material, it should, he considered, have a pressure put upon it in the form of work of no less than 20 tons to the square inch. He cast for him an ingot like that described by the Author, and he saw the ingot reduced from 10 feet in length to 9 feet; but even at that time there was only a pressure of 6 tons put upon it. By means, however, of his powerful hydraulic presses he obtained the other 14 tons, and he then came to the conclusion that he had a perfectly homogeneous steel. In 1878 he and his colleague, Mr. Martell, in investigating the subject of steel for ship-building and boiler-making purposes, visited the various steel-works in the Kingdom, and also the works where steel was being manipulated into various forms, and they were told by Mr. Webb, a man of great authority both as an engineer and steel-maker, that in order to obtain a thoroughly homogeneous and sound plate it should be worked from an ingot quite twenty times its thickness. That view was corroborated by another great steel-maker, Mr. Sharp, of Bolton. In 1885 he was instructed by the Committee of Lloyd's Register, which he represented, to visit the Continent and to visit the various works with a view to ascertaining their practice. In France he called at the Terre Noire Works, and there met the eminent chemist and metallurgist, Mr. Pourcel, who gave him a very different view of the method of producing a sound, solid homogeneous material. If not out of order, he should be glad to read an extract from the report that he had made on the subject:—

"Mr. Pourcel pointed out that what Sir Joseph Whitworth and others considered necessary, in the form of mechanical work to produce a sound piece of steel, could be equally well obtained by chemical means without any mechanical work at all. Mr. Pourcel was kind enough to show me his whole process In the

Mr. Parker.

> first instance he substitutes for the silicide of iron and manganese an alloy manufactured at the works, containing about 10 per cent. of silicon, 30 per cent. of manganese, and from 1½ to 2 per cent. of carbon. A certain proportion of this alloy is added to the metal at the end of the process, that is to say, before the metal is poured from the furnace to the mould; the two reducing elements act together, and at once combine with the whole of the remaining oxygen in the bath, preventing further oxidation of the carbon from taking place and forming a very fusible slag which is composed of a silicate of iron and manganese, and this slag rises quickly to the surface; the formation of carbonic oxide gas, which would otherwise form the blow-holes when the metal is cold, is thus prevented, and also the steel becomes purged of its injurious constituents, which pass off in the slag to the head or runner on the casting, and leave it perfectly sound and homogeneous"

He witnessed at those works not only large masses such as trunnions for guns, and even armour-plates, but also guns made by the process adopted at Terre Noire, and Mr. Pourcel had in his presence a hoop made, an ordinary casting, about 14 inches in diameter inside, 2 inches thick, and 4 inches deep. When it was produced from the sand, he thought that if it was placed under a steam-hammer it would fly to pieces; but it was passed through his process, annealed in baths of oil, and then bent double cold without the slightest flaw. On visiting the works of Messrs. Schneider and Co., the managing Engineer-in-chief, Mr. J. Barba, gave him his views on the subject. He said that, with regard to cast-steel *versus* wrought or hammered steel, so far as his experience had gone, he was not prepared to use cast-steel in preference to hammered steel for heavy and important parts; he believed that hammering a piece of steel did improve its quality considerably; but, on the other hand, he was not prepared to say that the results obtained by mechanical treatment, such as he had described, could not also be equally obtained by chemical means, and he believed that eventually this would be obtained. However, at Creusot no such results had yet been arrived at, and for some time to come hammered material must be adopted in place of cast for large pieces. Mr. Barba further explained that from experiments he had recently been making, he was led to believe that great changes took place in the structure or crystallization of steel during the process of cooling or transition from a fluid to a solid state, and that in making steel-castings, too little attention had hitherto been paid to this point. As an illustration, he cast an ingot of zinc, about 5 inches long, dividing it into three sections, which, by encircling water round the ingot mould, and other means, he caused to solidify under different conditions of cooling; the ingot was then broken into two pieces, and the fracture of each section showed a different appearance; the section of metal that had solidi-

Mr. Parker.

fied rapidly bore a granular or small crystalline appearance, whilst the section that solidified slowly bore a fibrous crystalline appearance, clearly proving that in order to obtain a casting of uniform structure throughout, it was necessary to make it of such a form as would admit of its solidifying uniformly, and to arrange matters so that the rate of cooling was such as would produce a structure giving the maximum of ductility, or to anneal it subsequently, so as to rearrange its crystalline structure. That was, in Mr. Parker's opinion, the most important point in connection with obtaining a solid steel ingot. Again, in the same year, he was instructed to investigate the subject of cast-steel *versus* wrought-steel for large crank-shafts and other important parts of marine engines. He had prepared a table to show that cast-steel without any work upon it was in its tensile-strength, in its ductility, and in its bending properties, very nearly equal to the best steel made by fluid compression.

TESTS of FORGED- and of CAST-STEEL and WROUGHT-IRON, to WITHSTAND TENSION, TORSION, and BENDING.

	Makers.	Tensile.		Torsional.		Bending.	
		Tons per Square Inch.	Elongation in 2 inches.	Twisting Moment.	No. of Twists in 10 inches.[1]	Dimensions.	Angle through which Bent.[2]
			Per cent.	Inch-lbs.		Inch Square	°
Forged steel.	Whitworth . .	26·25	42·6				
	Vickers . . .	27·00	38·7	3,432	12·8	1¼	180
	Siemens . . .	36·00	23·4	4,499	5·1	1¼	180
	Bolton . . .	35·28	35·5	..	..	1¼	112
Cast steel.	Spencer . . .	23·73	31·5	3,972	10·7	1½	77
	Jessop	28·13	..	3,756	11·3	1½	167
	Steel Company of Scotland . .	28·21	12·5	3,516	5·0	1½	195
	Steel from ingot .	22·68	9·0	3,168	5·2	1½	114
Wrought iron.	..	19·78	26·9	2,520	4·9		
	..	20·08	21·0	2,040	2·5		
	..	15·20	10·0	2,820	10·0		

Further he would simply say that one of the firms he visited seven or eight years ago was at that time commencing the making of crank-shafts, for marine engines, varying from 9 to 15

---

[1] The diameter of the torsional test-pieces was ⅝ inch.

[2] The Journal of the Iron and Steel Institute, 1883, Plates II and III.

Mr. Parker. inches in diameter. Since then, from two hundred to three hundred of those shafts had been made, and were now running in ocean steamers, and he had never heard of a single failure. That went far to prove that it was not absolutely necessary to have all the work referred to in the Paper put upon steel. Mr. James Riley, of the Steel Company of Scotland, read a Paper on the same subject in 1887. Before doing so and making his experiments, he held very much the same opinion that Mr. Parker held, together with Sir Joseph Whitworth and a number of other persons, that it was absolutely necessary to have a great amount of work put upon the material. He would quote, however, one short passage of Mr. Riley's Paper. "The teaching of all this seems to be, that if you want a strong steel, without caring greatly about its ductility, put abundance of work upon it; but if you desire a plate of medium strength and of high ductility, do not put an excessive amount of work upon it; and if you would increase the ductility, anneal it carefully after rolling."[1] Those were Mr. Riley's remarks after he had altered his opinion. Mr. Parker had a little while before endeavoured to demonstrate the same thing to his own satisfaction, and he had stated during the discussion, "To summarise the results of these experiments, he might say that he had an ingot made, 6 feet in length, and a piece cut from it 15 inches thick, another piece 12½ inches, another 10 inches, another 7½ inches, another 5 inches, another 3 inches, another 2 inches, and the last one, 1 inch thick. Those pieces of steel were hammered and rolled into ½-inch plates, and, when tested, the tenacity of the plate rolled from the large piece, 15 inches thick, was found to be 25·9 tons to the inch, with an elongation of 27 per cent.,[2] while the piece that had no work put upon it except rolling it from 1 inch thick to ½ inch, had a tenacity of 25·8 tons with an elongation of 26 per cent. in a length of 8 inches." That he thought was a pretty conclusive proof that something else besides work was required in producing a solid plate of a homogeneous character. He did not think it unnecessary to put work upon the steel; but was it necessary to procure all that elaborate machinery, and to go to so great an expense, for the purpose of crushing the steel up in its fluid state, with a view of getting it homogeneous, when it was very evident that this could be accomplished with much less work? He considered other matters were quite as important as work. In the first place, he thought a thorough knowledge of melting was necessary, and means should be taken by which ingots should be allowed to cool uniformly, thus preventing crystallization and the existence of initial stresses; and if any initial stresses existed in the piece after forging, means for relieving these stresses should be adopted, by annealing or otherwise. All those things were, in his opinion, of equal importance to the work put upon the material by the fluid-compressing process. He was sure that if steel-makers could produce a material, which was, beyond doubt, thoroughly homogeneous and sound, they would be conferring a great boon not only upon the engineering community of the country, but upon shipowners and underwriters, who had to pay enormous claims for the broken shafts to which reference had been made. Mr. Parker.

---

[1] The Journal of the Iron and Steel Institute, 1887, p. 126.

[2] *Ibid.*, p. 133.

Mr. JAMES RILEY said that the data in the Paper to which Mr. Parker had referred were very voluminous, consisting of many hundreds of tests, from which Mr. Riley had deduced the opinion that had been quoted. But he did not think it necessary even to go so far to establish the case which Mr. Parker had laid before the members. Even in the Paper now under discussion there was sufficient proof of the position which he had taken up. The Author had neglected one or two points of very great importance, one of which had been already pointed out by Mr. Ellis. He had stated (p. 108): "But in order to ensure that the tests from all parts of a pressed ingot shall give practically uniform results, except so far as local chemical composition and liquation of elements affect such tests, a pressure of from 12 to 15 tons is desirable." The particular point which the Author had mentioned only incidentally, but which Mr. Ellis had referred to specifically, and which was known to be of vast importance, required more consideration than had been bestowed on it. Probably it might have led to clearer conclusions on this point if the chemical analyses had been given. The Author had referred to 1881, and seemed to imagine that no progress had been made in the eight busiest years in the history of steel manufacture, and that plum-pudding ingots, like those represented in the diagrams, were now being made. Every one acquainted with the manufacture of steel knew that these were not proper representations of the ingots cast in any good works. If the Author's summaries were neglected, and his data examined, as at p. 139, the average results of his tests would be found; and without entering into much careful consideration, it would be seen at once that his deductions were false. In one place he had stated that the best of the unpressed ingot was not equal to the average of the pressed ingot. But, on looking at his statistics, it would be seen that the Mr. Riley.

Mr. Riley. greater uniformity was in the tests of the unpressed ingot. Whether taking the elastic limit, the breaking-stress, the elongation, or the contraction of area, it would be found that the unpressed portions were equal in strength to, if not better than, the ingot which had been subject to the barbarous treatment described, and they were also more uniform. The Author was confuted by the results which he had himself stated. Let manufacturers, therefore, not put down presses, even if it were assumed that there were only two perfect steel-makers in the universe. The Author appeared to have pleasure in pointing to the fact that, in looking at the elongation of the steel under test, it was in the amount of extension before fracture that the compressed ingot showed its maximum of superiority; and he had forgotten what no one practically engaged in steel-making in the present day should forget, that a piece of steel having only 0·35 of carbon would extend a great deal more than a piece which had 0·50 of carbon in it. Having ignored those elementary facts, he pressed upon the members the particular point that the elongations, which were quite normal for steels of the composition given, were so much to the credit of the pressed steel.

Mr. Vickers. Mr. Thomas E. Vickers held that the members ought to feel indebted to the Author for his description of the fluid compression of steel, especially as it afforded an opportunity to discuss the merits of a process which for years past had been talked about and extolled by technical school metallurgists, newspaper writers, and people not conversant with the proper theory or practice of the manufacture. Some years ago Mr. William Annable, who had been for six years in the employment of Sir Joseph Whitworth and Co., wrote a Paper "On the Compression of Fluid Steel."[1] In that Paper it was stated that pressure was maintained upon each ingot for twenty to forty-five minutes, according to size. It was also stated that all the ingots so pressed had cavities in the upper part of the ingot, and that into one of the cavities in a 28-inch diameter ingot, 270 cubic inches of water were poured. Mr. Annable gave theoretical reasons for those cavities with which Mr. Vickers did not agree. Pressure continued for so short a time must be useless for ingots properly melted. To be effective the pressure must be maintained until the whole of the steel was solidified, and that solidification must require at least two and a half hours in an ingot of 28 inches diameter. The pressure exerted must be sufficiently great to be capable of forging the constantly-increasing dimensions of the walls of the ingot, in order to attain solidity. The Author had stated that at the Abouchoff Works the pressure was maintained for three and a half hours on a 34·25-inch ingot. That increased time accounted for the better results obtained at the Abouchoff Works, compared with those described by Mr. Annable. If the linear expansion and contraction of steel in the molten state were identical with those in the unmolten state, the theoretical cubical contraction would be approximately 1 per cent. for each 500° Fahrenheit. It was unknown at what degree of heat steel was poured into the moulds, but if it was assumed to be 4,000°, the total contraction to the cold state should be about 8 per cent. From trials, he believed the total contraction to be about 9 per cent. Of that amount about 6 or 6½ per cent. was accounted for by the contraction of the exterior of the ingots, and about 2½ per cent. by the internal contraction. The supplying or not of that 2½ per cent. with fluid steel determined whether the ingots became solid or not. If steel, when poured into the mould, was in a proper condition, and of suitable chemical composition, it lay perfectly still in the mould, without any escape of gas, and the upper surface began to sink and form the so-called "piping," which was due to the supplying of steel to the parts contracting internally. In the case of mild steel, the surface generally cooled over, and formed a crust of varying thickness. The piping, however, went on underneath that crust, and formed what the Author described as a "pear-shaped cavity." To avoid that cavity without fluid pressure, a head should be put on the ingot to supply the necessary 2½ per cent. of fluid steel, and by that means absolute soundness would be obtained. If, on the contrary, the steel, when poured into the mould, was badly melted or in a condition conducive to the elimination of occluded gases, considerable ebullition would be noticed, followed by the rising of the upper surface of the steel as soon as it was no longer sufficiently fluid to allow the escape of the gas-bubbles. The bubbles, unable to rise, formed cavities called honey-combs. In the early days of the Bessemer and the open-hearth processes, he had seen steel quite frothy with the quantity of escaping gas-bubbles. Fluid compression would be absolutely necessary to make an apparently solid ingot of such material, but he doubted whether any pressure could make a really reliable ingot of it. Fig. 12 represented an impression from a section cut across the centre of a steel ingot, which he had cast without a head some six or seven years ago, to demonstrate to some engineers that steel ingots properly made had no zone of

---

[1] A copy of this Paper is in the Library of the Institution. [Tracts 8vo. vol 466.]

Mr. Vickers.

Mr. Vickers. unsoundness, and also to show the extent of the interior contraction of steel ingots. With the exception of the central pear-shaped cavity, the ingot was free from cavities. If that ingot had been supplied with the usual head, it would have been without any cavity. Fig. 13 represented the section of an ingot intended for a gun jacket. The interior part being cut out before forging, the contraction cavity in the centre would be in no way detrimental. The centre and upper portion of the ingot after removal were slotted through the middle, and an impression was then taken, so that the Fig. showed accurately the extent of the cavity. There were no honey-combs whatever. The advocates of fluid compression attempted to prove the necessity of the process, by the assertion that the gases which were driven off during the process were being eliminated from the steel. He was positive that all those gases proceeded from the carbonaceous and organic matter in the lining of the mould. When unpressed ingots were cast in moulds lined with similar composition, even when the thickness of lining was not more than $\frac{3}{4}$ inch, there was always an escape of gases, which burned at every outlet. The gases were given off more

Fig. 12.

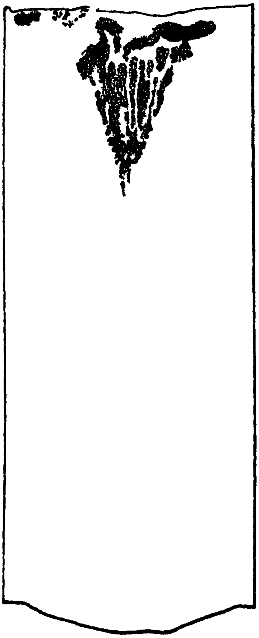
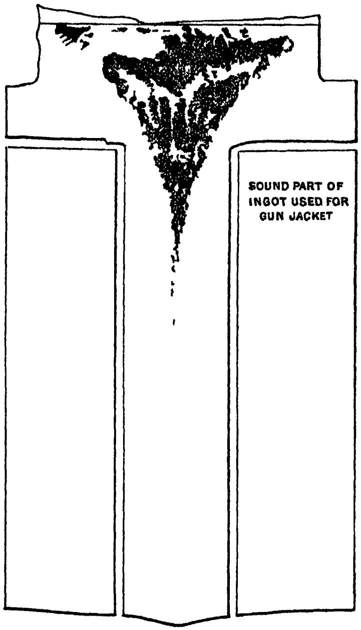


Fig. 13.



Mr. Vickers. rapidly during fluid compression, because hot particles of steel were forced into the pores of the lining, and thus got more quickly into contact with the gas-producing materials. The Author had stated, and Mr. Vickers believed he was in the main correct, that the occluded gases were eliminated as the steel solidified. As it required over three hours for the ingot described by him to solidify, it followed that gases were given off constantly during that time. In the early stage of the process a solid wall was formed, and partially forged by the pressure. That wall surrounded a molten mass in the centre. Was it conceivable, then, that gases eliminated after the formation of this wall could be driven through it, and, above all, without leaving a trace of their passage? The Author had stated that the usual contraction in length alone was 1½ inch to the foot, or 12½ per cent. He also directed attention to a statement, made by Sir Joseph Whitworth in his evidence given in 1879 in support of his application for a renewal of his patent, that, "when the pressure is applied to a column of fluid metal, whether it is solid or whether it is in the shape of a tube, in five minutes after the pressure is applied, the whole mass, whatever its length, will go down one-eighth of its whole length, the air being pressed out." Imagine 12½ per cent. contraction in five minutes, and at least 8 per cent. to follow by the time the steel had cooled. If manufacturers were to believe that statement, they must come to the conclusion that Whitworth steel was quite frothy. The fact that the renewal of the patent was unopposed showed the estimation of its value in the minds of steel-makers generally. If the observations of the Author, from which he derived the amount of the linear contraction, were correct, he would only say that his steel must have been also full of froth, and that accounted for the miserable specimen of an unpressed ingot which he had exhibited. It was preposterous that, because he had no experience of steel properly treated, he should state that the average of steel ingots made by others should be as utterly bad as those of which he had experience. The Author referred to the acicular structure of steel ingots cooled without pressure. As such ingots were afterwards forged, what good could there be in having that structure removed during casting? As regarded the saving effected by making steel without a head, he thought, as the head was used for attachment during forging to the almost necessary porter-bar, the convenience of handling outweighed the loss caused by the cost of melting the steel necessary for the head. The masses he described must be very inconvenient pieces to deal with. He now wished to call attention to the tensile-tests of the compressed

Mr. Vickers.

Figures in Roman type, tons per square inch.
„ Italic „ percentages of elongation.

33·49 *17·85* 33·49 *16·98*	23·44 *2·80* 32·82 *12·38*	22·77 *3·25* 32·15 *8·39*	29·47 *12·34* 31·48 *6·76*	29·47 *11·64* 32·82 *10·03*	28·13 *12·49* 32·82 *13·55*	29·47 *21·09* 32·82 *17·43*
32·82 *21·80* 32·15 *17·58*	32·82 *16·39* 31·48 *11·42*	30·14 *4·91* 25·45 *2·85*	34·83 *5·05* 30·81 *4·03*	32·15 *5·00* 25·45 *2·80*	32·82 *15·92* 30·81 *8·83*	32·82 *14·34* 33·49 *17·47*
32·15 *16·43* 32·18 *17·80*	28·13 *6·20* 26·12 *5·71*	27·46 *3·82* 26·12 *4·28*	28·80 *5·18* 28·13 *5·46*	30·81 *6·89* 26·12 *4·26*	31·48 *14·21* 30·14 *8·20*	32·82 *18·24* 32·15 *15·60*
32·15 *16·79* 32·15 *15·81*	31·48 *10·49* 28·80 *6·01*	31·48 *9·70* 27·46 *5·25*	31·48 *13·83* 27·46 *5·50*	31·48 *8·71* 26·12 *4·29*	30·81 *9·20* 27·46 *5·03*	32·82 *21·09* 32·82 *17·35*
32·82 *16·74* 32·82 *14·77*	30·81 *17·11* 28·80 *15·98*	30·14 *9·17* 28·13 *10·82*	28·13 *6·42* 29·47 *11·52*	30·14 *10·23* 28·80 *10·96*	29·47 *8·70* 28·80 *18·84*	32·15 *18·46* 32·82 *16·26*
33·49 *16·92* 33·49 *15·65*	29·47 *19·17* 29·47 *23·35*	28·80 *15·12* 27·46 *17·37*	28·80 *16·20* 24·78 *9·83*	29·47 *16·42* 27·46 *13·87*	29·47 *16·96* 28·13 *18·53*	33·49 *15·11* 33·49 *16·46*
32·82 *16·33* 30·14 *22·81*	26·12 *11·85* 27·46 *18·71*	27·46 *12·53* 24·16 *7·87*	15·40 *2·67* 24·78 *8·41*	27·46 *20·69* 26·79 *13·56*	27·46 *13·48* 28·13 *27·60*	32·15 *17·95* 30·14 *22·07*

Mr. Vickers.

ingot. He would not compare them with those of his uncompressed ingot, as comparison with an ingot so badly made was useless. In the Table on p. 156 would be seen the Author's figures placed in the position from which the corresponding test-pieces were taken. The figures in ordinary type were tons per square inch, the italic figures percentages of elongation. It would be seen that the two bottom series, the sides and the top, were, with a few irregular exceptions, much better than the interior ones. It was said that to avoid irregularities, fluid compression must be adopted. The great irregularities of the figures pointed to the contrary conclusion, as Mr. Vickers held that the Author had succeeded in producing an ingot of a most irregular and unreliable nature. Supposing those irregularities to be still present when the ingot was forged into a shaft or gun, how would it be possible to tell by tests, which must be taken from the ends, whether the forging was a good one or not? In the Author's case the ends were better than the centre; but, in the case of an unpressed ingot with a proper head, it could be assumed that the end tests would not be better than central ones could they be taken. The cause of the bad quality of the central parts was attributable to the fact that as steel crystallized it endeavoured to throw off the carbon, silicon, phosphorus, sulphur, &c. The part remaining fluid, therefore, was continually being supplied with an excess of those elements. The parts which cooled first must therefore be purer than those which cooled last; as the cooling must take place from the sides and ends, these parts must be the best part of the ingot.

Mr. Roberts-Austen.

Mr. W. C. Roberts-Austen said the Author had stated (p. 85), that "the occluded gases are supposed to be eliminated only at the moment when the metal changes from the liquid to the solid condition, as occurs in the oft-quoted and well-authenticated examples of hydrogen from platinum, of carbonic oxide from palladium, and of oxygen from silver under like conditions." Having had some experience of experiments on the occlusion of gases by metals, he might say that, in the case at least of palladium, the evolution of the gas did not occur necessarily at the moment of solidification. The hydrogen, in fact, came off from the palladium at the temperature of boiling-water, or even lower. Again, the condition under which hydrogen was retained by palladium was not a simple question of solution of the gas in the metal, but of the absorption of a certain amount of hydrogen by a definite hydride of palladium. It was true that, in the case of silver, the oxygen gas did appear to be evolved at the moment of solidification, and in that case there was the remarkable fact that

Mr. Roberts-Austen.

the presence of a small amount of copper appeared to be sufficient to prevent the silver absorbing the oxygen at all. It was possible that silicon in iron might act in the same way. It had recently been asserted that Bessemer metal contained an inordinate amount of nitrogen—nitrogen, of course, accompanying the air which was blown through the metal; while the open-hearth metal, on the other hand, was richer in hydrogen, it having been protected from the direct action of air by the layer of slag which covered its surface; and there had been some experimental evidence that the superiority of open-hearth metal for certain purposes was due to the absence of nitrogen. In the manufacture of the Mannesmann tubes it had been found that hydrogen, and a little nitrogen, was released from the metal, probably from cavities, at the ordinary temperature; but, with regard to the escape of gases from compressed metal, it should be remembered that Graham had demonstrated that solid iron was freely permeable at a red heat by hydrogen. There was an expression in the Paper which gave him an opportunity of saying a few words which he had long desired to offer to the Institution. He referred to the use of the words "temper" and "tempering" by engineers. An old author writing some hundred years ago, said: "The most useful property of steel is that of becoming very hard when ignited and plunged into cold water, and the colours which appear on the surface of steel slowly heated, direct the artist in tempering or reducing the hardness of steel to any determined standard." It seemed to him that engineers had rejected that definition of "temper," or at any rate had confused the words "temper" and "hardening." No doubt the French word "trempé" was in a certain sense responsible for much of that confusion; but "acier trempé" meant "plunged" steel or hardened steel, and not tempered steel. The Americans recognized that, and very properly called hardened steel "quenched steel." So distinguished an authority as Lord Armstrong, in a Paper "On the treatment of Steel for the Construction of Ordnance, and other purposes," read before the British Association in 1882, constantly spoke about tempering in oil, when the expression oil-hardening should have been used; and, in the following sentence, quoted from his Paper, the use of the word tempering was far from clear:—"On carrying the reheating to still higher degrees (than the melting-point of zinc) the effect of the previous tempering gradually diminished, but was not altogether obliterated, even when the temperature was raised to the bright red heat at which the steel had been immersed in the oil for the purpose of tempering." It might be urged that when a certain shade of hardness was assumed, far lower than that which the metal would have attained had it been cooled rapidly from a high temperature by plunging in water, "temper" was given to the metal at a single operation by plunging the hot metal in oil; it might be said to have acquired a certain "temper," but he thought it would be much better if the word oil-hardening were used. Then, again, the Author, at p. 108, had made what he thought was a very unfortunate use of the same word. He had said: "The figures are selected from some hundreds of records, embracing casts from both open-hearth and crucible steel, and are made upon tempers ranging from 0·3 per cent. to upwards of 1 per cent. of carbon." That suggested that the temper of the metal solely depended upon its degree of carburization; the fact being, as was well known, that the amount of carbon present simply enabled the steel to receive a certain degree of hardness by absolutely definite thermal treatment. No one, he thought, would dream of speaking of definite tempers of steel containing from 0·3 to 1 per cent. of manganese; yet, within those limits manganese shared with carbon the power of enabling iron to become very hard when rapidly cooled from a high temperature, and of being tempered by reheating. Those, however, were only very small points in an elaborate Paper; but he took the opportunity of appealing to engineers—he thought it was time that metallurgists should make that appeal—to use the word "tempering" in a consistent way. He remembered reading a Paper in the Minutes of Proceedings of the Institution which was for some time unintelligible to him, because tempering and hardening had been confounded. Mr. Roberts-Austen.

Colonel H. Dyer said that as he was for some years associated with the firm of Whitworth and Co., he had had a good opportunity of ascertaining the full advantages of fluid-pressed steel, and although he did not pretend to say that the Whitworth steel was the best in the market, for there was plenty of steel quite as good, certainly none in England, nor on the Continent, was better. But the excellence did not depend upon fluid pressure. It was true that the fluid pressure was applied, but in the case of the Whitworth steel the excellence was a case of *post hoc*, and not of *propter hoc*. To explain the reason why pressure did not do what the Author of the Paper had stated, it was necessary to compare the fluid-pressed ingots as they were made with the others. When the metal for an ingot intended to be submitted to pressure was run into the mould, the fluid metal in contact with the cold mould commenced at once to solidify, and the head did the same shortly after the plunger was brought in contact Colonel Dye

Colonel Dyer. with it. The consequence was that the ingot very rapidly assumed the condition of a cylinder with a fluid centre, with more or less hard exterior surfaces; as these surfaces lost the heat necessary to keep mild steel in a semi-fluid condition, a zone of metal more or less hard was formed all over the exterior of the ingot and the interior remained in a fluid condition, and so remained, in the case of a 30-inch ingot, to his certain knowledge about three hours—he could not say how much longer—after it had been cast. This zone was described by the Author as followed: "The unsoundness extends towards the centre, in the 30·75-inch ingot represented in Fig. 1, to about 3 inches from the surface, both at the sides and over the bottom of the ingot." Assuming that description to be correct, although he could not accept it as a description of any ingots except the Author's, there was a zone of unsoundness of 3 inches, the blow-holes forming as the metal solidified. If the pressure came on just at the moment of solidification, that was just during the time that the zone was becoming honey-combed, it was possible that a pressure might be brought to bear sufficient to force the gases from the 3 inches of the outside of the ingot into the channels prepared for its reception. It was possible to assume it, although he did not think it was so, but if it were done, there would then be an envelope of 3 inches outside of perfectly sound metal all over the ingot, the inside still remaining fluid, and therefore in a condition in which blow-holes could not be formed, as in this condition the occluded gases were not eliminated. But as this fluid metal solidified, the gases would be eliminated if there were any occluded in the metal and blow-holes would be formed. The pressure went on, and it was asserted that the fluid metal inside cooling gradually eliminated the occluded gases, and that these gases were forced by pressure through the solid metal, now formed all over the exterior surfaces of the ingot, into the channels prepared for them. If it were credited that the gas could be forced by any known pressure through 3 inches of solid metal, there still remained about 20 inches of fluid metal to be disposed of. Taking the 4th, the 5th, or the 6th inch, there must come a time when reason would rebel against the possibility of believing that any amount of pressure could force gas through solid and partially solid material, such as the outside of the ingot then consisted of; in fact, it was implied that the already solidified envelope of the ingot, notwithstanding the enormous pressure put on the top of it, opened to let the gases pass, and then closed without leaving any trace, and that this opening and closing arrangement was continued for several hours.

He could not believe any such thing could occur. In proof that it did occur, the Author stated that he saw long flames coming out and burning. That was true, but if the Author would make an unpressed ingot he would see flames precisely similar. He had himself seen many hundreds of both pressed and unpressed ingots cast, and could state from personal observation, that there was no difference between the flames coming from a pressed and from an unpressed ingot, the flames all came from the material lining the mould, nothing proceeded from the steel inside. The question was, what became of the gases? No doubt gases in the best melted steel did exist in small quantities, but what became of them? To explain this, it was necessary to compare the pressed and unpressed ingots:—the unpressed ingot, when properly cast, had a head in the form of a cone, the apex of which in an ingot 20 feet long, was from 24 to 36 inches deep. These cones were very regular in shape, the apex being exactly on the axis of the ingot. In the case of a 30-inch ingot about 20 or 25 feet long, if the head was cut off about 14 or 16 inches below the cone it would be found perfectly sound. If the pressed ingot was cut off at the same distance from the base a large hole would be found. He was certain that no one who had cast those ingots would deny the fact that every one of the pressed ingots had a hole at that point, and it was there that the gases collected. The Author had declared that his ingots, made in Russia, were absolutely sound, and he referred to an ingot 66 inches long, which had been made up into a certain number of trunnions, every one of which was perfect, there being no waste whatever. That certainly was extraordinary. He had never seen an ingot, pressed or unpressed, in which there was not some unsoundness and some slag about those parts. At p. 119 the Author said: "It is usual to state that such metal is some 18 per cent. stronger under a tensile-stress than the metal made without fluid compression." He had had daily opportunities of testing both fluid-pressed steel and steel made without fluid pressure, and the results of many hundreds of tests showed that, provided the chemical composition was practically the same, there was not an atom of difference between the forged fluid-pressed steel and the forged unpressed steel; the ductility, the strength, and everything else were as nearly as possible identical. In regard to the chemical composition of the different parts of the fluid-pressed ingot and the unpressed ingot, the same remark applied. The facts connected with that subject should be enough to do away with some of the unreasonable statements that had been made—statements which he was sure those who had Colonel Dyer lonel Dyer. most to do with fluid-pressed steel ingots would be the first to deny. What was claimed for the fluid-pressed steel ingot by Whitworth and Co., was, that by means of the fluid pressure they could get a larger quantity of the ingot for useful purposes; but no one would profess that he could alter the quality of the steel by pressure, that he could make good steel into bad, or bad steel into good by any pressure that human means could put upon it. It stood to reason that it could not be done; and one proof that the pressure had not the effect some persons supposed was that the fluid-pressed steel was never made with high carbon. If the pressure did all the good claimed by some of its advocates, the pressure would surely be far more useful in fluid high-carbon steel than in viscid, comparatively thick, mild steel containing a low percentage of carbon; but curiously enough it was never used when steel contained a high percentage of carbon. He hoped his remarks would not be misunderstood. He was not saying that the Whitworth fluid-pressed steel was bad, or indifferent, or worse than any other; on the contrary, he believed there was no better steel in the market, either in England or abroad, than the Whitworth steel, but the fluid pressure had absolutely nothing to do with its quality.

. Walker. Mr. B. Walker considered it very creditable to the steel-makers of the country that the Author should have to go back eight years to find an example of bad steel. He believed if it had been put under pressure it would have been bad still. He agreed with Mr. Vickers in thinking that the examples given by the Author were not such as were found in daily use. Thousands of tons of perfectly sound steel were made every year. According to the Author seven-tenths of the steel made in the country was such as he would not advise to be pressed. Would anybody maintain that all the boilers that had been made in the country were unsound? They were no such thing. Sound ingots could be, and were, made without any compression. Colonel Dyer, he thought, had proved too much. No doubt, leaving cost out of the question, steel might be improved by putting it under pressure while in a liquid condition; but the head must be cut off, as Mr. Vickers had pointed out. With regard to large, say 100-ton, ingots, the maker was thankful when they were made, without having the trouble to squeeze them in the liquid form by hydraulic pressure. The deserved reputation of Whitworth steel depended mainly upon two causes; the best possible material was put into the furnace, the best workmen were employed, and the material was carefully forged under a hydraulic press. The Author, he thought unwisely, had

Mr. Walker. separated the forging and the casting. If Sir Joseph Whitworth and Co. had never adopted the forging-press, he believed their compressed or liquid steel would long ago have been forgotten. It was the adoption of the forging-press, and the other causes he had mentioned, that had given it such a position. Mr. Vickers, in dealing with the cooling of steel, had forgotten to mention one point. The process that took place in cooling an ingot was the reverse of what took place when milk cooled. When milk cooled the cream came to the top; whereas when an ingot cooled, the worst went to the top, and the best to the bottom. Instead of trying to cover it up, the best steel-makers tried to keep it hot so as to make the best of it, and to get the bad material into the head. Mr. Ellis, for example, lighted a large fire on the top of the ingot, kept it warm, and nursed it, so that it evolved the sulphur and other objectionable gases, bringing them to the top. Steel could not be fairly worked unless treated as a fluid, when it was hot and ready for the hammer or the press. If the ingot was allowed to cool gradually and come to a uniform temperature, and then put under the forging press, all that was possible was done towards improving its quality. The piping shown by Colonel Dyer generally went much lower down; both sides of the piping were of the same heat, and when the material was properly heated in a soaking-pit or furnace, the parts were closed together, and a much less quantity was wasted than would at first sight seem to be the case. The top was used for inferior work. Mr. Vickers stated that he used it as a balance weight; but that was rather expensive. He thought there must be some mistake about the Author's statement respecting the 10,000-ton press. If he meant 10,000 tons force, separating the top and bottom cross-heads from each other, it would not work for a week. He at first thought that it meant foot-tons—total capacity. In the enormous press that he was making for Mr. Krupp there were four 18-inch pillars, and the highest quality of steel was used; but it was only called a 5,000-ton press. The press he had made for Mr. Ellis was only called a 4,000-ton press, and it also had 18-inch pillars. The Author evidently was willing to trust steel with a much higher tensile-strain than he was; he said that his 8,000-ton press had only four columns 12 inches in diameter; this gave a working strain of about 20 tons to the square inch, and he thought it was unreasonable. He only called his hydraulic forging-presses, such as he had made and of which he was making a large number for various firms, with pillars 10 inches in diameter, 2,000-ton forging presses.

Mr. Hall. Mr. J. F. HALL said he was disappointed with the Paper. He had expected to hear a Paper relating to hydraulic pressure after the

Mr. Hall. fluidity of steel had ceased. It appeared to him that a step had been taken backwards rather than forwards. He asked permission to read a short extract from a Paper which he had read before the Institution of Naval Architects in April 1884:—"As for that fascinatingly-worded theory, 'fluid compressed steel,' I think I am not wrong in saying it is now entirely exploded and proved to be a delusion. This is how it was once described in regard to crank-shafts: 'When hydraulic and pneumatic machinery was properly adapted, all crank-shafts would in future be made out of molten steel under pressure, as by doing so, while it was in a molten or plastic state, the interstices between the crystals occupied by metallic vapours were filled up, and it became a solid mass.' If this wonderful result took place, what need was there for the future hammering or squeezing which followed this process? In fact, the whole theory is an absurdity, and I am given to understand, on reliable authority, that it has some time since ceased to be practised, at least on large cranks or parts of cranks, at the very place where it originated."[1] The Paper was freely discussed in 1884, and since that date very little had been said about fluid compressed steel; a great deal more had been heard of the pressure of steel by hydraulic presses after the steel was made, and that he thought was a more fitting subject of discussion than one which had been almost put on one side by the majority of steel-makers, he might almost say, throughout the world. He hoped the Author would discuss the treatment of steel by hydraulic pressure after it had become solid. The way in which he had worked out the present communication was certainly very much to his credit, whatever differences of opinion there might be respecting it. If he would only write a similar Paper about the further action of hydraulic presses upon steel ingots, he was sure the members would be pleased to hear him.

Sir Robert Rawlinson. Sir ROBERT RAWLINSON said that the workers of China-clay who had to get air out of a lump of clay, knew that they could not remove it by pressure; they therefore did it by frequently slicing it through and kneading it, so as to liberate any gas or air that might be inside. His own idea was that in the case of an ingot of steel with air or gas cavities, hydraulic power might compress them into smaller cavities; and could do no more.

Mr. Davis. Mr. J. H. DAVIS said the Author appeared to think that compressed steel, as made by Sir Joseph Whitworth and Co., eliminated entirely any flaws that there might be in the ingot. He wished to mention one instance that had come under his own observation where that did not occur; it was the case of a compressed-steel hydraulic cylinder supplied to him by that firm for making hydraulic presses. There had been great difficulty in obtaining cast-steel cylinders as quickly as they were wanted, and he induced Sir Joseph Whitworth to make a cylinder of his compressed steel on trial. After long delay the cylinder was delivered, and to all appearance it was an excellent piece of work. The metal seemed without a flaw; the cylinder was turned and completed for its work, with the exception of slotting out the heads. Most engineers would know that there were bolt-holes with the heads recessed for putting in the bolts for fastening the gland on the top of the cylinder. During that operation he was sent for to see what had occurred. A piece of metal about 4 inches square had dropped off the head of the cylinder, leaving the surfaces as smooth as glass. Of course the cylinder was useless, and no more of them were made. The impression on his mind, and on the minds of others who saw it, was clearly that there had been a gas-bubble or something of that nature in the casting, and that the effect of the pressure to which the ingot had been subjected was merely to elongate or spread out the gas-bubble over a larger surface, and that immediately the edges of the metal were touched by the slotting tool the piece dropped away. That, he thought, showed conclusively that the system advocated by the Author did not eliminate any flaw that might be in a steel ingot. He should be glad to hear from the Author in what way the flaws were eliminated by pressure from fluid-compressed steel. Mr. Davis.

---

[1] Transactions of the Institution of Naval Architects, vol. xxv. p. 177.

Mr. JOHN W. SPENCER said it had been stated by the Author that absolutely sound cast ingots could not be made; but he thought it had been proved that this was not the case. At any rate, he could state from his own experience that with careful management of the furnace, both as regarded the temperature and its chemical action and reaction, a thoroughly sound ingot could be produced absolutely free from blow-holes. The presence of occluded gases in steel, their nature, and subsequent expulsion, was, perhaps, difficult to explain; but under any circumstances they could be got rid of so as to prevent blow-holes by knowledge and careful attention. In his opinion, the strength of steel, taking tenacity and ductility together, was not dependent, as commonly supposed, upon the work put upon it. This had been his view for many years, and had been amply proved. He had arrived at this conclusion from a study of the laws of crystallization, and treating steel passing from the fluid to the solid state as subject to those laws. The finer the state of crystallization, so much greater would be the cohesive action, Mr. Spencer.

Mr. Spencer.

—	1					
	10-inch parallel.		5-inch parallel.		2½-inch parallel.	
Mark of test	O 1,981	O 1,982	O 1,983	O 1,984	O 1,985	O 1,986
Original diameter of specimen . . . inch	0·993	0·996	0·999	0·998	0·997	0·959
Fractured diameter of specimen . . „	0·88	0·64	0·64	0·64	0·66	0·67
Original area . . sq. inch	0·7744	0·7791	0·7838	0·7822	0·7806	0·7223
Elastic limit, tons per sq. in.	13·56	12·89	12·53	13·12	13·38	13·90
Breaking stress „ „	24·78	24·63	24·89	25·11	25·27	25·34
Contraction of area per cent.	21·46	58·72	59·16	58·88	56·17	51·19
Ultimate elongation per cent. in lengths of—						
2½ inches	17·2	44·8	44·0	42·0	39·2	36·8
5 „	17·0	31·8	33 0	30·6	..	..
10 „	17·1	26·3	..	..	..	..
Appearance of fracture—						
Silky . . . per cent	..	100	100	100	100	100
Flaw . . . . „ „	20 outside					
Finely granular „ „	80					

1. Results of material without mechanical treatment.

and the resistance of the material to either pulling or bending stress; and when this state of maximum cohesion of the crystals had been arrived at, whether in the initial stage of casting or during the manufacture of the material to the finished article, no amount of work, either by forging or other mechanical means, made it stronger. As illustrating this, he cited figures from the above Table, being a series of tests prepared by him for the information of Mr. T. W. Traill, Chief Engineer of the Board of Trade Marine Department. A 4½-inch ingot was cast in the ordinary way, and then cut into three pieces. One piece was

Mr. Sp

2						3					
10-inch parallel.		5-inch parallel.		2¼-inch parallel.		10-inch parallel.		5-inch parallel.		2¼-inch parallel.	
Q 539	Q 540	Q 541	Q 542	Q 543	Q 544	Q 557	Q 558	Q 559	Q 560	Q 561	Q 562
1·00	1·00	1·00	1·00	0·997	0·997	0·998	1·00	0·994	0·994	0·998	1·00
0·73	0·74	0·72	0·72	0·73	0·73	0·66	0·65	0·65	0·665	0·66	0·66
0·7854	0·7854	0·7854	0·7854	0·7806	0·7806	0·7822	0·7854	0·7760	0·7760	0·7822	0·7854
17·62	17·50	17·10	18·18	18·41	17·41	11·41	11·36	11·50	11·50	11·41	11·36
28·47	28·40	29·10	29·44	30·35	29·33	25·82	25·69	25·60	25·60	26·25	26·14
46·71	45·25	48·16	48·16	46·38	46·38	56·26	57·75	57·37	56·58	56·26	56·44
36·0	32·0	36·4	37·2	28·8	32·0	41·6	45·2	39·2	44·4	39·6	38·4
29·0	26·0	28·0	27·6	..	..	31·6	35·2	30·2	33·0	..	..
22·3	21·2	..	..	..	..	25·0	28·5	..	..	..	..
100	100	100	100	100	100	100	100	100	100	100	100

2. Do forged. 3. Do. forged and annealed.

treated without any mechanical means being used, the same as with intricate steel castings; the second was forged down to 1¼ inch square, and the third, being similarly forged, was afterwards annealed to enable a fair comparison to be made with the first, which was also annealed. On comparing the results of tests, it was found that the forged but unannealed piece was higher in tensile strength, but lower in ductility, than the first, but when annealed there was practically no difference between the two, or, if anything, the unforged steel had the advantage. This showed most clearly that the same results could be obtained by other

Mr. Spencer. means than mechanical, and that the result of forging was to increase the tensile-strength at the expense of ductility. For the manufacture of plain forms, such as shafting, &c., hammering or pressing was the cheapest, and the forging-press was undoubtedly the best tool for the reduction of large ingots; but this did not apply to more irregular forms. They could, however, be produced as simple castings, possessed of all the qualities required of the best steel forgings, without a particle of mechanical work having been put upon them, by simply conforming to the requirement of the natural law, to secure the smallest possible state of crystallization instead of the largest, though, not to be misunderstood, he was not referring to close-grained steel, as shown in the fracture of hammered or hard steel. Forging was perhaps necessary, because cheap, but it was barbarous, nevertheless; and it was as difficult to compute the irregular strains set up in the mass by irregular heating and cooling as it was to know the damage done by severing the continuity of the crystallization in the mass through rough treatment between hammer and anvil. There was no need for this, as the cast material could be produced in every way equal to the forging, and, in the case of large masses especially, much better. He was sorry the results of the tests of the forgings were not given in the Paper, as the comparison between an ingot cast in the ordinary way and one manipulated by hydraulic pressure of several tons per square inch, otherwise, was not a fair one. In his opinion, the latter case was equivalent to forging under favourable conditions. If the result of the tests of forgings made from the unpressed ingot had been submitted, and those from the pressed ingot, then a fair comparison of the value of the two might have been arrived at. The Paper had given him much information on the subject of hydraulic forging and the compressing of steel; but it strongly confirmed him in the opinion he had expressed, namely, that all the pressure put upon the molten ingot, or by hammer or forging press, would not produce a better material than could be had without the application of those mechanical means.

Mr. Reynolds. Mr. EDWARD REYNOLDS wished to offer a few words from a different point of view. He had been afraid that he should be obliged to take a different position, because so much had been said in favour of the particular process of one particular manufacturer, that the constant silence of other persons appeared to amount to a tacit assent to pretensions which he held to be unfounded; but after what had taken place in the course of the discussion, and especially after what Colonel Dyer had stated, all the pretensions founded

Mr. Reynolds. on the practice of playing tricks with steel instead of making it properly, must vanish. No one would wish to dispute the claim made by Colonel Dyer, that as good steel was made in the works to which he had referred as anywhere else, but not because of any peculiar method of manipulation. He had feared that he should be obliged to quote examples showing that in one important application at least that manufactory had been peculiarly unfortunate, but that was not now necessary. He was about to approach the theoretical part of the business, which he much preferred to take up before the Institution. His first knowledge of the subject of fluid compression was derived from "Abridgements of the Specifications relating to the Manufacture of Iron and Steel, 1858." His attention had been called by Mr. Vickers, at an early stage of their acquaintance, to a patent by James Hollingrake, May 15th, 1819. Mr. Reynolds wished to refer to it, because in the Paper the introduction of fluid compression was claimed for the wrong people. This official record was as followed:—

A.D. 1819, May 15—No. 4371.

"Hollingrake, James—'Casting metallic substances into various forms and shapes with improved closeness and soundness in texture' The metal is cast in a suitable mould, and great pressure applied by moveable piston or plugs arranged in any convenient manner, to insure the molten particles being compressed into close contact"

That process, he was informed, had been used for many years. When Sir Joseph Whitworth's patent was taken out, he was told that it had been used regularly for twenty years in the works of the Broughton Copper Company, Manchester, and so far as there was any merit in the invention, it ought to go to the original Author. He should like very shortly to state what he thought was the reason of the honey-combing that sometimes occurred, which all the nostrums that certain people had brought out were intended to obviate. Evidently from the point of view of these would-be inventors, it did not matter what they did to steel. They might cast it under pressure, or under vacuum, or blow air upon it, or put gases into it; it never seemed to occur to their minds to make it properly, and let it alone. There had been a great deal of misunderstanding as to the nature of the cavities in the steel, and the way in which they were formed. On the occasion of the reading of a Paper by Sir Joseph Whitworth, before the Institution of Mechanical Engineers in Manchester, in July, 1875, he tried to explain the way in which the cavities did arise, and as what he then said was endorsed by the late Sir William Siemens, he might

Mr. Reynolds. be permitted to read an extract from the report. After mentioning the stopping that was formerly necessary in the Bessemer process, as Mr. Vickers and others had mentioned, he went on to say,[1] "But good work might be done, without the use of a press, by 'dead melting;' and it was desirable to trace the nature and effect of this. In melting by the crucible, it was not sufficient to get the material well heated and thoroughly fluid; but after it had arrived at that condition it must be left for some time in the furnace to 'kill' it. In a lecture upon fuel, delivered by Mr. Siemens at the Bradford meeting of the British Association, attention had been called to the remarkable discovery that there was a limit to the heat at which combustion was possible; and that this limit, at which oxygen and hydrogen might be mixed without burning—which it had been proposed to call the heat of dissociation—had been fixed by Mr. St. Claire Deville at about 4,500° Fahrenheit. The application of the same principle to the combination of oxygen with carbon, silicium, &c., appeared to furnish an explanation of the nature of 'dead-melting,' which might assist in the more general production of sound ingots. In the ordinary methods of steel-making a great heat was obtained, and in the Bessemer process the heat was still greater; so that in either case a near approach to the heat of dissociation was soon reached, and chemical action was arrested before being completed. But if the metal were cast in that state, it would soon cool down to a temperature at which chemical action would again come into operation; and gases would be evolved, giving rise to honey-combing. The remedy was to keep it melted for a considerable time, so that the chemical action, which was then very languid from the near approach to the heat of dissociation, might have time to become complete. An instructive illustration of this principle was afforded in the working of the regenerative tank furnaces for steel-making. If these furnaces were worked at too low a heat, the charge would become softened so rapidly that the metal would set (soft steel having a high melting point), and much time and patience and a great heat would be necessary to remelt it; and inasmuch as the intense chemical action, due to a low heat, applied to the furnace as well as to the charge, the slag would run into the sand bed of the furnace as into a sponge, and when remelted probably a considerable part of the charge would leak out. This made it necessary to take from ten to twelve hours for a process which might otherwise be completed in three or four hours, and to use a very high

---

[1] Institution of Mechanical Engineers. Proceedings, 1875, p. 300.

Mr. Reynolds.

heat in order to avoid cutting the furnace to pieces." He thought that was the explanation of the action. Any one who had watched the ingots in the early stage of the Bessemer process would have seen that they appeared to be quite still for about five minutes after they were cast; but that after they became cool to a certain point the rising began. It used to be prevented by covering the metal with sand, upon which was placed an iron plate secured by a "cotter." It was possible to conceive that if such a moderate force were sufficient to prevent the rising, a still greater force might do it better, and in some cases cause re-absorption of the gases, and this appeared to be the idea of the advocates of fluid compression. But the true remedy, as had been suggested, was to melt the material properly and let it alone.

Mr. Traill.

Mr. T. W. TRAILL observed that he was not a steel-maker, but he could speak of the mechanical properties of steel after it had been tested, and that was how engineers judged whether steel was suitable or not for structures like the shafts of engines. It seemed from the Paper to resolve itself into a commercial question whether 30 per cent. of the ingot was to be thrown away, or whether all the ingot should be utilized. It was clearly stated by the Author that the results of the tests of the whole ingot were practically uniform, and such as could be used. It had been admitted by the steel-makers who had spoken that they could not use a very large portion of the ingot; but he did not think that many had committed themselves as to what proportion of the ingot must be thrown away. He could only say, without being an advocate for one process or the other, that in all the mechanical tests he had seen of fluid-compressed steel, he had never come across an indifferent specimen. The tests of compressed steel which had come under his observation had not, however, been so numerous as those of uncompressed.

Mr. McDonnell.

Mr. ALEXANDER McDONNELL could not say that he had had much experience in the casting of steel; but he knew a good deal about forging it, and there were one or two points that he desired to mention. In such a case as that mentioned by Colonel Dyer, where the sides of the ingot were bent downwards so as to enclose the cavity in the inside, he should say that the whole of that metal so bent down was entirely worthless, independently of its being honey-combed. After the metal had begun to crystallize, if work were put upon it, either by a hammer or by a hydraulic press, it would certainly be seriously damaged, and he thought the same effect would follow if the pressure upon the top of the ingot were such that, after the sides of the ingot had commenced to set, it was

Mr. McDonnell. sufficient to crush them, and force the gas through. That, he thought, might be expected, if it was considered what took place on crystallization. After any metal which had begun to crystallize was crushed, its continuity was destroyed. He did not think high temperature alone did any harm to steel; but if steel were forged at a high temperature a great deal of harm was done. It was not the high temperature that did the steel harm, but the forging at the high temperature; because while the particles of metal were beginning to set and crystallize, their continuity was broken. If strength was wanted, at all events in steel, the metal should be crystallized with rapidity, so that the crystals should be very small. If crystallization took place very slowly, the crystals were large. With any ordinary solution, say the solution of alum, or anything that crystallized easily, the crystals were small if crystallized rapidly, but if it were crystallized by slow evaporation, they were large. If, while the crystals were forming, they were disturbed and broken up, a loose material would be the result. That was shown in the setting of mortar. If while mortar was setting it was broken, it would not set again. Steel was not like wrought-iron. At a welding heat it was in a state of crystallizing, and if any kind of work was brought upon steel near that temperature, damage would be done; and if pressure were brought upon steel just at the moment it was setting it would be damaged. He was not at all prepared to say that, if pressure could be brought to bear upon the fluid part of it, some good might not be effected. He thought that was an open question; but if the pressure was brought upon steel during the time of its setting it would certainly be damaged. Reference had been made to the use of the word "tempering." He quite admitted that the word had often been used in the way to which exception had been taken, but all engineers who were accustomed to treat steel understood perfectly well what "tempering" was. A piece of spring steel, heated to a fairly high temperature, and dipped in water, became as brittle as glass; but if it were heated to a low red heat, and left to cool slowly, its high hardness would be lowered, and that was what engineers were accustomed to call "tempering."

Mr. Cowper. Mr. E. A. Cowper observed that the Author had obtained great experience in the only two works in which the compression of fluid steel was carried out on a large scale; and he had shown great liberality in giving so much information—a liberality deserving of imitation. He had hoped to hear from steel-makers a statement of the cause of bubbles being formed in ingots, and a frank explanation of how they could be prevented; but he had listened

Mr. Cowper.

in vain for such information, though it had been asserted in more than one quarter that they could be avoided. That was hardly conclusive or satisfactory. However, it was so much the more the duty of every one having opportunities of observing the changes that metal underwent by treatment to do what he could to solve important facts that bore upon any unsolved question. He well remembered, in 1868, with Sir William Siemens, watching a puddling furnace in which gas was used, and they saw the little jets of carbonic oxide gas jumping up through the liquid metal all over the surface, in jets perhaps 1 inch to 2 inches high, and only a few inches apart. They saw no flame at first, as the atmosphere of the furnace was neutral, but he proposed to open the door wider, and let in a quantity of atmospheric air, and then they saw the flames burning perfectly. That he considered a very pretty illustration of what was now well known, namely, that the oxygen from the oxide of iron "fettling" of the furnace united with the carbon in the "pig metal," and this formed carbonic oxide gas, which escaped from the liquid metal until the iron "came to nature," or was converted into wrought-iron, when it was time to "ball it up." To apply that fact to the case of steel, if it were not that the analysis of the gas, contained in the bubbles in steel, had been proved by some authorities to be chiefly hydrogen, he should certainly have thought, that the same thing took place in the ingot when it had come down to the puddling temperature, which was much lower than melted steel. But as the gas in bubbles was chiefly hydrogen, he thought the Author of the Paper must be correct in his supposition (pp. 85 and 86), that the gas was occluded as long as the ingot was quite liquid, and separated on or about the time of its solidifying; otherwise the common rise of the metal in the ingot mould some time after casting, could not be accounted for, nor the explosions nor sudden liberations of gas, when cooling in the Whitworth press, in which no doubt the cooling was more uniform owing to the peculiar lining of the ingot mould. With regard to the question of hydrogen in the bubbles, it had puzzled many persons, but if steel could occlude hydrogen, he thought the source of it was evident. Common atmospheric air contained moisture at all times, sometimes in greater quantity, sometimes in less; but water was invariably present in the condition of vapour or steam; then, in the Bessemer process, thousands of cubic feet of air were forced through a charge, and with it a considerable quantity of water, which was of course at once decomposed, thereby producing carbonic oxide and hydrogen, so that the whole of the charge had great opportunities of taking up or

Mr. Cowper. occluding hydrogen; and hence the hydrogen in the bubbles. It would be highly interesting to observe if there were more bubbles when the air was damp, than when it was comparatively dry. (He might mention, that cold-blast furnaces worked much better in cold dry weather than in damp weather.) Now the compressing of everything that was compressible in the ingot-mould, must be productive of good; because, if the gas was there, the bubbles would be made much smaller, namely, to $\frac{1}{746}$ the size, or $\frac{1}{9}$ the diameter, by 5 tons per square inch being brought to bear on them, so that the gaps and holes in the cold ingot would be of much less size than if it had undergone no pressure. Moreover, the gas might be taken up or occluded by the metal under such great pressure, like carbonic acid gas dissolved in soda-water. He did not for a moment believe that bubbles were passed out through the sides of the ingot, as they were pressed equally on all sides. He believed that if the pressure was put on quickly enough the top outside edges of the ingot would not turn down inside on cooling. It seemed reasonable to suppose that the forcible pressing down all the top metal upon the metal below, was even a better plan than that commonly practised in making large iron castings where a light wrought-iron rod was kept moving or pumping up and down in a "git" or "runner" to feed liquid cast-iron into the mould as the metal shrank in cooling. In forging a piece of steel himself, he had often noticed the peculiar smell that came from the steel, but whether this was gas he could not say. That steel should be "run dead" or "left to kill" there was no doubt; and he knew that in an open hearth it could be manipulated, and even tested to some extent, to see if it was in a right condition, and quite quiet or "dead." This could be done better than in a vessel in which the carbon was furiously burnt out by a blast, where a little over-blowing would produce a quantity of burnt iron (oxide of iron) which would combine with the carbon of the spiegel when it was put in, and produce frothing or bubbling. The fact that it was not commonly necessary to press steel, containing much carbon, again pointed to the fact that any oxide of iron that might have been present at any time had all been absorbed by the carbon and given off as gas. Even in making iron castings, it was advisable to let the metal become quiet in the ladle, and not to pour it too soon after it was out of the cupola. To conclude, he thought the evidence was conclusive that Whitworth steel castings were very good, and that the Author had proved his case, as shown by the statements of his opponents.

Mr. Sowerby.

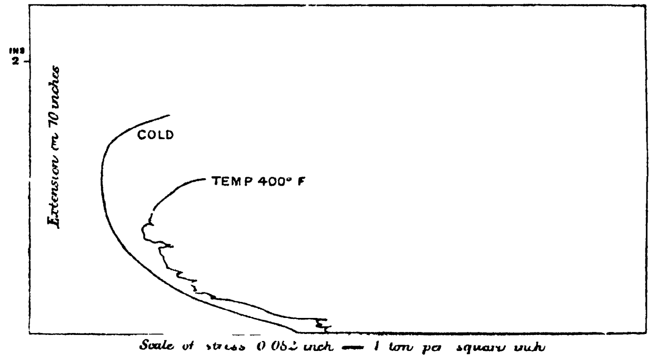
Mr. W. Sowerby said that the subject of the manufacture of steel had been before the Institution on several recent occasions. He had taken intense interest in the discussions, for although he was not practically engaged in the manufacture of steel he had studied the subject for many years. Steel was a superior kind of iron, which had undergone a very complicated process in its conversion. Mr. Vickers had referred to the piping at the top, and Colonel Dyer had also referred to the same subject, pointing out that when the column or ingot was compressed, the gases or globules were collected in a cavity at the upper part of the casting, involving a loss or wastage of about 30 per cent., or one-third of the metal on both plans. Allusion had also been made to tempering and hardening. Steel might be hardened without being tempered, but it could not be tempered without being first hardened; and tempering in oil, which was a method of great antiquity, both hardened and tempered the steel at the same time. It was the amount of labour put upon every class of steel, the Persian or the Toledo blade for example, that very largely gave it its quality. In those cases, there was a superior kind of iron to work upon, but the labour bestowed upon it added greatly to its excellence. No doubt, the better the ironstone the easier it was to produce excellent steel, but it was not certain that excellent steel could not be produced from inferior ironstone. When the Cleveland ironstone was discovered in 1845, samples of it were sent to experts in London, by whom it was pronounced of no value for smelting. Meanwhile, Messrs. Bolckow and Vaughan were making pig metal out of it, and now 10,000,000 tons were annually smelted, and a considerable quantity was being converted into steel. As to the question of compression, the Author had stated that that process decidedly improved steel. Colonel Dyer maintained that open-hearth casting was as good. Who should decide between the two? A 10,000-ton press was an enormous machine to compress steel. If the metal was liquid like water it would be impossible to compress it. It was not, however, in a fluid state, but in a state of crystallization, the crystals being finely divided into many millions of parts. It was certain that when heavy pressure was put on the top of a column or ingot of molten metal, whether of steel or any other metal, and there were cavities or globules in the interior of the mass, these globules would find vent at the nearest points to the outside of the ingot, namely, the sides, and would not make their way to the top; hence Colonel Dyer's theory would be at fault. But as the globules were pressed out towards the sides, the passages or channels through which they would

Mr. Sowerby. escape would become defects in the metal. Though the width or thickness and breadth of these channels might be only $\frac{1}{10000}$ inch, they would be defects, and the greater the number of globules the greater the number of such defects; which would always remain, no matter what amount of pressure was brought to bear upon the metal. Sir Robert Rawlinson had referred to the difficulty of getting rid of air cavities out of China-clay when undergoing the process of moulding; but he seemed to be unaware of the simple method adopted for doing this, namely, having perforated moulds, lined with thick felt, which allowed the air and moisture to escape when pressure was applied, and prevented the clay from being forced out of the mould. The same system had been adopted for making artificial stone blocks out of granite chips; but Mr. Brunton had a chemical process similar to Pourcel's method of improving steel.

Mr. Head. Mr. John Head agreed with Mr. Cowper that instead of endeavouring to drive gases from molten steel, the gases which forme the bubbles should not be imparted to the steel in its manufa ture. The presence of gases in steel, according to his experienc was due to the gases in combustion being mixed with the metal i fusion; and this mixing could be avoided in open-hearth furnace by adopting heating by radiation; this subject had been s thoroughly explained by Mr. Frederick Siemens, that it was un necessary to deal with it in detail on the present occasion; and h would only add that in the case of glass, when melted by radiation the disappearance of blow-holes was complete. On a previous occasion he had produced before the Institution bottles made in furnace heated by contact, and in furnaces heated by radiation, in which this fact was made evident. He did not think it possible to expel gases from steel partly solidified, by subjecting it to compression in powerful hydraulic presses; but he considered that forging ingots with such presses was preferable to the usual method of hammer ing, owing to the action of the presses being more gradual hammering, as usually practised, tended to damage the metal, eac stroke making a deep indentation on the surface, which destroyed its continuity; but the damage would be less if the blows wer not so heavy, the ingots being cogged down more gradually. I speaking of the treatment of steel, he would lay stress upon the word "gradually," whether hammering or rolling was applied to the metal; and in the latter case, as it was passed from groove to groove, too great a bite should be avoided. The new process of rolling invented by Mr. Mannesmann fell in with these requirements as to compression, and, moreover, by it the metal was subjected to a considerable but gradual torsion. The amount of compression and torsion to which metal was subjected in the Mannesmann mill increased from the time an ingot entered the mill until it left it; one part of the ingot rolled was subjected to a certain amount of torsion and another part to a greater amount of torsion at one and the same time, so that between these two points there was a gradual increased torsion, producing the soundest steel that had ever been made. The Mannesmann mill had already been briefly described in a Paper read before the British Association, by Mr. Frederick Siemens, and it would soon be at work in this country, when further information regarding it would be available. **Mr. Head.**

Mr. JOHN GOODMAN noticed that some remarks had been made in the Paper with reference to the strength of Whitworth steel ingots, **Mr. Goodman.**

FIG. 14.



——		Cold	Hot (400° Fahrenheit).
Diameter	inch	1·128	1·128
Sectional area	square inch	1·00	1·00
Reduction in area	per cent	46 2	47·2
Extension on 10 inches	,,	16·0	11·7
,, ,, 2 inches at fracture	,,	34·6	34·0
Elastic limit	tons per square inch	21·97	20·45
Maximum stress	,, ,, ,, ,,	34·03	31·83
Work of fracture in inch-tons per cubic inch		4·99	3 24

Both specimens showed a fine silky fracture.

but not to the same material after it had been rolled and forged. He had made some tests on this point, the results of which were shown in Fig. 14. The curves represented the stress-strain

Goodman. diagrams of a piece of Whitworth steel, which was exactly 1 square inch in area, and turned down from a 1½-inch bar received direct from Sir Joseph Whitworth and Co. When tested cold it gave a stress of 34·03 tons per square inch. When tested hot it gave a very remarkable diagram, but one that he had frequently found when steel was so tested. Instead of the steel-yard of the testing-machine floating easily as with an ordinary cold test, it went up and down in a most irregular fashion. Although the test was carried out slowly, and the pressure was applied perfectly regularly by means of the Hydraulic Company's mains, it was impossible to keep the steel-yard floating. The specimen was enclosed in a sheet-iron casing covered on the outside with asbestos. The heated gases from a gas-furnace passed through the casing and thus formed an air-bath. It was heated up to 400° Fahrenheit. The autographic diagram was taken in the same way as was usually done, with cold tests; it then gave a tensile-stress of 31·83 tons per square inch. The elastic limit was also lower. Both the elastic limit and the ultimate strength were about 6½ per cent. lower when the metal was hot than when it was cold. Amongst many other pieces of steel tested in the same way one especially gave interesting results. The diagram was even more serrated and irregular than the piece of Whitworth steel, and, curiously enough, it had a higher tensile-strength when hot than when cold. It gave 49·35 tons when heated to 400° Fahrenheit, and 44·69 tons when tested cold. Another piece of steel was tested, much milder than either of the others, and gave similar results; it had been found that the smaller the quantity of carbon in the steel, the more regular the diagram became. At first he feared that the apparatus used for testing at high temperatures interfered with the wire from which the stress-strain diagram was obtained, but further experiments with some rolled bronze showed that regular curves were always obtained with that material. The greatest care was taken, and he believed that the curves were perfectly correct. They might possibly throw some light on the peculiar point brought forward by Mr. Stromeyer on a former occasion before the Institution, when he showed that steel when worked at a blue heat was much more liable to damage than steel at either a high temperature or a low temperature. It was generally considered impossible for air to be pressed through the outer surface of the ingot while in the press. He did not think that was at all impossible. He might be permitted to refer to an experiment which he made a few years ago. A red-hot boiler-plate, about 6 feet by 4 feet, and ½ inch thick was taken, and paraffin oil

Mr. Goodman. or benzoline was poured on the top. The oil ran through the plate while red-hot, and burned on the under side of it. Great precautions were taken to prevent the paraffin spreading over the sides; the oil ran clean through the plate. If oil, which was a comparatively viscous material, would get through red-hot iron, why should not air get through it? The oil was not subjected to pressure, hence when there was a pressure of 6 tons per square inch on steel, why could not gas, which was much less viscous, be pressed through the sides of the ingot? Those who had witnessed the process of fluid compression of steel were, unfortunately, very few in number, because Sir Joseph Whitworth carefully kept the process secret for some years. Mr. Goodman had had the pleasure of seeing it on several occasions, and he had noticed repeatedly how the gas came out at a very high pressure, issuing in long streams of flame with a hissing noise similar to the lucigen light. That would have been impossible unless the pressure at the top of the ingot had forced it out. It was a familiar phenomenon to see water pressed through hydraulic cylinders. When cast-steel, cast-iron, gun-metal, or practically any metal was used for hydraulic cylinders, on even only 1 ton per square inch being reached, dew formed on the surface, and it was only prevented by hammering the outside, or allowing the metal to rust. If water at a low pressure came through in that way, as in the case of oil, why should not hot gases be pressed through?

Professor Unwin. Professor W. C. Unwin asked the Author to explain what he meant by saying that the elastic limit under certain conditions was so-and-so. He had given Tables containing the elastic limits of pressed and of unpressed steel; but Professor Unwin ventured to say that there was not a word in the Paper to show what that elastic limit meant. He might venture to guess that it meant that, at the stresses named, there occurred the very large permanent set which occurred in most rolled materials at some stage. There was this to be said about that so-called limit—that, so far as he could see, it very much depended on the time and other conditions of testing. At any rate it would be a great advantage to know how the test was made if it was given as an indication of quality. He thought it highly desirable to do in this country what had already been done in Germany, where conference after conference had been held of the most able engineers and experimentalists, with a view of determining exactly under what conditions observations should be registered. In this country they were registered with all sorts of instruments, and with very varying degrees of accuracy, and he was not sure that engineers were not being misled

Professor Unwin. by the way in which the tests were being made. That was a point coming almost daily before him, and a point in which he thought English engineers were rather following behind. They wanted to know a little more what they were doing. The diagram exhibited by Mr. Goodman (Fig. 14), was quite new to him. The autographic diagram of steel tested hot was certainly very remarkable —so remarkable that at first he very much hesitated to believe that a diagram of that kind really indicated properties characteristic of the material. Mr. Goodman, however, was a very careful experimenter, and he had no doubt that the test was made as carefully as possible. Still, he should like to know a little more of the details before accepting a diagram of that kind as characteristic of the material. He knew of no reason why a stress diagram from hot iron should always be serrated and one from cold iron always smooth, except possibly this: He had tried during the past year to make a hot test in the same way as Mr. Goodman seemed to have proceeded. He was asked to make some tests of material when hot and when cold, and it had occurred to him that, after all, the air-bath was the best way of doing so. Twenty-five years ago he experimented with hot oil, but there was so much trouble with it that he was glad not to have the oil to use, and he tried an air-bath. He found it impossible with any air-bath round the bar to keep a uniform temperature, or to know exactly what the temperature was inside the air-bath; and he had come to the conclusion that the air-bath, after all, could not be trusted. He tried a double and triple air-bath, but still could not get a steady uniform temperature. The specific heat of the air was low, and changes of temperature occurred too quickly to be indicated by any thermometer. He ventured to throw out the suggestion that the changes of temperature might account for considerable serrations in the diagram. There might also be other reasons which he did not know. He had been lately testing some materials with hot oil, and he certainly did not recognize any results similar to those obtained by Mr. Goodman.

Mr. Goodman. Mr. JOHN GOODMAN said he had found the same difficulty, as that to which Professor Unwin had referred, in keeping the temperature of the air-bath constant; but, by means of a small fan revolving at a high speed, he had completely overcome the difficulty. He should be very glad if any members of the Institution would inspect the apparatus, and, if there were any errors in it, he would do his best to correct them.

Mr. Anderson. Mr. W. ANDERSON, of Erith, said that he was probably the only person in the room, besides the Author of the Paper, who had seen

Mr. Anderson.

the Abouchoff fluid-compressed steel plant in operation frequently, and he was glad to confirm the correctness of the Author's description and of his conclusions in every way. It was with the utmost diffidence that he ventured to criticize the observations made by Colonel Dyer with respect to the process of cooling melted steel in the mould. He explained how the metal solidified all round the surfaces of the ingot, and then asked if it were possible that pressure could have any effect, or that occluded gases could escape through the solid metal. Surely Colonel Dyer did not wish it to be believed that the metal set dead cold and hard round the surface of the mould! Though solid, the metal was still at a very high temperature, and plastic in the extreme; witness the manner in which it yielded subsequently, at a much lower temperature, to the forging press; and therefore in the mould it would, and did, succumb to the pressure brought upon it. Again, Colonel Dyer seemed to be unaware of the well-known fact, established by the researches of Graham, Professor Roberts-Austen, and others, that gases passed through highly heated solid metals with ease; and not gases only, but liquids and solids also. Mercury, for instance, passed, at ordinary temperatures, rapidly through tin, and carbon, which had never yet been fused in the manufacture of steel by the process of cementation, penetrated through and through thick iron bars when at a comparatively moderate temperature, and Mr. Goodman had just stated how readily petroleum passed through red-hot boiler-plate. There was nothing surprising, therefore, that gases occluded in ingots should make their escape easily through the solidified walls, especially as the rate of transfusion increased with the increase of temperature and pressure. The formation of a cavity in the extreme top of the compressed ingot, as described by Colonel Dyer, might possibly occur when the pressure was inadequate; but the Author had been careful to state that to attain success the pressure must be effective. He was certain, at any rate, that the cavities spoken of did not arise at the Abouchoff Works, or, if they did occasionally occur, they were so near the surface that they disappeared in the inch or two which had sometimes to be removed from the top end of the ingot. After all, why was the bottom end of an ingot, or for the matter of that, any casting, sounder than the top? and why were huge heads cast on when special soundness was aimed at? It seemed to him that the practice had arisen from a knowledge, derived from experience, that the pressure due to the head made sound work throughout the mass. He believed, however, that pressure applied to the still fluid steel had the effect of preventing the evolution of the

Mr. Anderson. occluded gases; for it was known that the quantity of gas which could be occluded in a liquid depended on the pressure, as was so well illustrated in the case of common soda-water alluded to by Mr. Cowper. All knew that, so long as the pressure was maintained, no gas bubbles could be detected; but the moment the pressure was relieved, the liquid became full of gas cavities, which a reapplication of the pressure was competent to obliterate. Mr. Walker, with whose arithmetical difficulties he had much sympathy, considered that if forging by hydraulic pressure had not been introduced, nothing more would have been heard about fluid compression, because, as Mr. Anderson presumed, the universally acknowledged success of forging by hydraulic pressure had given, in Mr. Walker's opinion, a spurious support to casting under fluid pressure; but the Abouchoff Works had, as yet, no forging-press, and could not have been misled by it. His own experience of forged steel, made by the most eminent makers, did not coincide with that of Mr. Walker, who, however, seemed to have spoken of small ingots only. Serious defects, which were the initial defects of the ingot drawn out and almost obliterated, but which still were solutions of continuity, frequently occurred; and, in long pieces of steel, it was possible to tell which had been the top end of the ingot by the prevalence of drawn-out air-bubbles there. But Admiral Kolokoltzoff was no believer in squeezing defects out of sight; he aimed at absolute soundness; and although it might be possible, as Mr. Spencer had stated—and certainly no one had a better right to make such an assertion—that sound ingots might be produced by extreme care, experience, and he might almost say, by intuitive genius at each stage of the process, the steel-makers of England, judging from his experience of their products, did not possess these qualifications. The Admiral had not found his own people superior in that respect; hence he had, at great cost, and in the face of persistent opposition, adopted a process which made the production of sound ingots of great size a certainty. It had been admitted by Mr. Vickers that a large portion of an ordinary ingot must be cut off, as much as a quarter of its length, he believed, if the rest was to be perfectly sound; but was it realized what an increase of plant was involved, if, to obtain a sound 40-ton ingot, a mass of 53 tons weight must be cast? He did not think the Author claimed that fluid compression had any effect on the quality of the steel itself, except in so far as that, by preventing the formation of mechanical imperfections, it enabled the metal to stand with certainty the stresses which its chemical composition should enable it to bear; and he could say, from his own personal knowledge, that since the adoption of the system at the Abouchoff Works a very few inches, if any, had now to be cut off the end of the ingots, and that a cracked or burst ingot, once so common, was now unknown. He had no doubt it would be retorted that the Russians had defective ingots because they made inferior steel, and did not know how to manipulate it; but to such objections he would reply that experience had shown that Russian steel, like Russian iron, was inferior to none—witness the four 16-inch columns which had successfully carried a working load of 10,000 tons, and that the Abouchoff Works had had a far wider experience of producing large steel ingots than any English firm. General Campbell, when Director of Artillery, had told him that iron was being used in the construction of English guns because no steel-maker in England could produce large steel forgings, a statement he demurred to altogether at the time, for he believed that had they been asked for they would have been produced; but eighteen years ago ingots of crucible steel of 40 tons weight were being cast at the Abouchoff Works (and those who had seen the operation were not likely to forget the sight), and being forged under a 50-ton hammer into guns of unrivalled excellence. After ten years' experience, and without a forging-press to mislead it, the Russian Admiralty, under the advice of the distinguished officer who had managed the Abouchoff Works for a quarter of a century, was now expending a very large sum of money in lengthening the fluid press, so as to take in 60-ton ingots; the authorities were building two 30-ton open-hearth furnaces, arranged to melt up the large accumulation of damaged ingots produced under the old system, and were laying down a powerful forging press, which would supply the means of producing steel such as only the Whitworth Company could now produce; and he ventured to prophecy, in the face of the somewhat contemptuous adverse criticism which the Paper had evolved, that, before many years were over, Manchester and St. Petersburg would no longer be the only places in the world where large masses of steel were prepared and worked by what, he was convinced, was the only rational and certain process. Mr. Anderson.

Lord Armstrong.

Lord ARMSTRONG said he had attended for the purpose of learning rather than of instructing, and he was hardly prepared to enter upon the subject in such a way as to give any useful information. One point had arrested his attention, an observation that had fallen from Mr. Spencer as to the equivalence of fluid pressure with forging. He could not admit that there was any analogy between the two cases. Forging was obviously a process by which work

Lord Armstrong. was put upon a material. That work consisted in the movement of particles, which seemed to have the effect of altering the crystallization; whereas the other was simply a case of statical pressure, which produced no motion of that kind. The forging might be called a kneading process; the other was simply a statical process, producing no work upon the casting, inasmuch as the density of the material was not altered, and no movement was communicated to the particles. It might be considered that there were three cases of defects affecting ingots as they were cast. One was the formation of air-bubbles, another was the collection of impurities at the upper end of the ingot, and the third was the formation of surface-cracks. As far as air-bubbles were concerned, it would be admitted that the dimensions of those bubbles must be enormously reduced by the process of fluid compression, and to that extent it was clear that the application of fluid pressure must be highly beneficial. But then it had been asserted that it was quite unnecessary to have air-bubbles formed at all. Whether that was correct or not he would not venture to say, but if air-bubbles were not formed at all, fluid compression did not appear to have any application in this connection. With regard to the next point, it would generally be admitted that not only did the air-bubbles tend to rise to the top and accumulate there, but the impurities of the material also rose to the top, and if that were true, and it did not appear to be disputed, it was quite true that the quality of the impure material which rose to the top could not possibly be altered by fluid compression. Therefore, under any circumstances, it appeared to him necessary that for special purposes the top of the ingot must be cut off. No doubt a frothy matter which rose to the top might be consolidated, and perhaps rendered more useful, but unless the impurities that also went to the top could be removed it was evident that a certain portion of the ingot ought to be sacrificed. As to the cracks, which were undoubtedly very troublesome, he thought the only cause that could be assigned for their formation was the inequality of cooling—that the external part of the ingot cooled more rapidly than the interior, and was therefore pulled asunder, and a number of small cracks were formed. Unless there was some peculiarity in the mould in the process of fluid compression, there was no reason why the same cracks should not be formed under both processes; at least he could not understand any difference. He should be glad to be informed as to any reason why there should be less equal cooling under a process of fluid compression than under the ordinary process. On the whole, although he did not dispute that there was a considerable advantage in fluid compression, as far as the prevention of air-bubbles was concerned, he did not see that in other respects the advantages claimed for it had been fully established. He did not, however, pretend to have the same experience as others, and he therefore advanced his ideas without any very great confidence in them. **Lord Armstrong.**

Mr. Greenwood. Mr. W. H. GREENWOOD, in reply, observed that the ingots prepared at the Abouchoff Works, and referred to in the discussion, were represented by photographs on the table, and Fig. 1, p. 87, and they did not vary materially from Fig. 13, p. 154, presented by Mr. Vickers. Those ingots were not unfair representatives of a very large number that had come under his personal observation in this country during the past year. They might be taken to be a fair average sample: they differed so little from Mr. Vickers' examples that he was willing to accept Figs. 12 and 13 for the purposes of the discussion, since he could not recognise Mr. Vickers' distinction between the sound portions of an ingot and the unsound portion or head which he cut off and rejected; for in the pressed ingot the whole of the metal (ingot and head) introduced into the mould constituted the ingot, and could be used for the purpose of the forging without any rejection. He was in no way a representative of the Whitworth Company. He had no authority to speak on its behalf, and no wish to do so. He had no interest or responsibilities, commercial or otherwise, in the Whitworth patent or in the firm, or any other firms, which would lead him to speak in that character. His only desire had been to present such information and such data as would enable the members to arrive at a satisfactory conclusion upon the disputed, and, possibly, yet very debateable question of the value of the fluid compression of steel. The Paper itself had received, as was to be expected, sharp criticism, but he was by no means in the position which Mr. Hall had attributed to him, that of having a desire to retire from his position. Nearly every steel-maker who had had any experience with large ingots had admitted that there was a top end of the ingot which was not sound; and the photograph No. 2 on the table, therefore, stood unimpeached as representing an absolutely sound cast ingot of mild steel, such as was not produced by any other process. No speaker, with the exception of Mr. Walker, who had of course cast a great many ingots, had said that he did, could, or would undertake to produce a similar ingot by any method yet introduced other than the "barbarous" method of fluid compression. Then as to forgings, marvellous as the statement had appeared to Mr. Ellis, no one had ventured to say that he would attempt to produce two such forgings as he had referred to, that would pass the

Mr. Greenwood. tests imposed by Russian inspection upon such forgings from an unpressed ingot of the dimensions quoted. Nor were they picked samples. The trunnions were not mere odd ones; they had been manufactured by hundreds at the Abouchoff Works. They were made constantly and regularly, and a faulty trunnion would lead to an extensive enquiry. Mr. Ellis had referred to the fact that as yet the compression process was in the hands of two firms only, who could not, therefore, be presumed to be possessed of the whole steel-making wisdom of the world. Such was the fact, but it would not be so long. It was equally the fact, however, that forging-presses were at work at one of the places he had referred to upwards of twenty years ago, and they were as much in advance of the hammers at that time as the present forging-presses were in advance of the hammers of the present day. Did it follow, because that firm maintained a monopoly, that it was wrong throughout those twenty years, but that now, when all firms were putting down large presses, that it suddenly became right? He had referred to various steel-makers who had opened up negotiations for the supply of pressing plant, and Mr. Ellis had stated that he himself applied to Sir Joseph Whitworth for licenses, or for some arrangement, but that Sir Joseph had declined all overtures of that character. The method was at present in the possession of two firms only, but it was an open secret, which he had expected to come out in the course of the discussion, that before the present year expired the world would know of the existence of another large plant for fluid compression in one of the largest existing works. Some doubt had been thrown upon the statement (which Mr. Anderson, however, had confirmed) that unclean forgings were every-day productions. If they were not, he would only ask why lathes were daily constructed of enormous capacity, taking off hundredweights and tons of metal from heavy forgings before they presented clean surfaces? That could not be considered as belonging to the exigencies of modern forging; it was due to faults in the surface itself. He had been met with the objection that in an ingot cast in the ordinary way a large amount of impurity was separated by the liquation of the impurities towards the centre and top of the ingots. He had never questioned the operation of liquation or the separation of impurities. That quality was known to those who worked with steel compressed ingots before steel-makers in England had generally recognized the fact. If it was an advantage, he supposed, however, that the ingot, which he had cast without pressure, and represented by Fig. 1, was subject to liquation, as in the case of any others. Yet comparisons were made from the lower or improved portions of such ingot with the whole length and volume of the pressed ingot; and, giving them all the advantages of liquation, by rejecting one-third from the top of each ingot, yet the comparison was highly favourable to the pressed ingot. It would be seen by the Tables, comparing the bottom of the unpressed with the bottom of the pressed ingot, or Series I of the tests from the former with Series I of the latter, and so on, comparing the ingots always at the same horizontal sections (Appendix V), that in the pressed and unpressed ingots, the strength being the same, the mean ductility at the bottom of the unpressed one was represented by 14·83 per cent., and the pressed one by 17·29 per cent. In the case of the next section above, that was, Series II of the tests from both ingots, the ductility was 10·93 per cent. in the unpressed, as against 17·43 per cent. in the pressed ingot. The disparity increased more and more rapidly as the top sections were approached. He did not see, therefore, that liquation had done very much towards injuring the argument that he had adduced. He was glad to agree with Mr. Parker on several points. He had advocated slow cooling of the ingot. Mr. Greenwood did not think the ingot mould (Figs. 3 and 4) was ill-adapted to the purpose. It was a comparatively porous cellular arrangement lined with badly-conducting material. The top and bottom faces of metal were brought in contact with burnt clay. It was not a bad arrangement on the whole for securing what was wanted. He agreed with Mr. Parker as to the desirability of saving the large insurance losses arising from fractures in connection with marine shafts. Anything which would obviate that evil could scarcely be estimated in money value. If there was anything in which the pressed metal was supposed to have had more than ordinary success it was when so applied. Steel shafts were a specialty in which the metal had been signally fortunate. It had been said that more than work was necessary to produce a homogeneous ingot. He thought he had proved that beyond doubt. He had spoken in the Paper of an alteration of volume of from 8 to 12 per cent. Mr. Vickers had given 2 per cent. as the total alteration affected by fluid compression in the volume of the ingot in question. How much work did that represent? There were all those blow-holes to fill up? How much work did fluid compression put on the steel afterwards? But he had in the concluding part of the Paper acquiesced in that view by advocating the making of guns from larger masses of steel, the steel ingots being cast under pressure, in the first instance, and then requiring considerably less work or forging to

Greenwood. be put upon them. Mr. Parker, reading from a report of Mr. Pourcel, attributed the production of blow-holes to reactions going on in the metal itself, whereby carbonic oxide was produced. That view was also apparently adopted by Mr. Reynolds. But in the Paper he had stated that blow-holes were found to contain carbonic oxide only in very small quantities. Surely, then, that gas could not give rise to their presence to any large extent; the holes were largely occupied by hydrogen—hydrogen, not coming from any reaction within the metal itself, nor derived from any direct action of impinging flame upon the metal, but from contact with furnace gases. He would refer to the observations of Mr. Head to state that the ingots to which he referred were many of them made in radiating furnaces. Believing as he did in radiating furnaces, he did not, however, regard them as a cure for unsound ingots. He attributed unsoundness to occluded hydrogen coming from furnace gases in some form or other. Mr. Riley had reminded him of a fundamental axiom that steel with 0·4 per cent. of carbon would have a higher ductility than steel with 0·5 per cent. of carbon, thinking that he had forgotten it. He had not forgotten it, and he had not forgotten another fact, that steel with 0·5 per cent. of carbon, the other conditions being the same, would have a greater tensile strength than steel with 0·4 per cent. of carbon; but, under the altered condition of compression, steel with 0·4 per cent. of carbon had a higher strength as well as a higher ductility than the steel containing 0·5 per cent. of carbon. The pressed ingot was taken of the milder temper, since he was afraid that if he took the ingots so that the pressed one would be the harder of the two, he should be told that the harder ingot would always cast sounder than the milder one, and he therefore took one with 0·4 per cent. of carbon for the pressed ingot. He also desired to eliminate all factors which could possibly be eliminated, and he therefore had steels practically of the same strength in the two cases, which left him in a position to compare them with reference to ductility only. Mr. Riley had also complained, notwithstanding the three specific references on pp. 108, 112, and 128 of the Paper, that he had not explained the phenomena of compression on the theory of liquation. It was true that he was not able to give an explanation on that score, and he left it to the ingenuity of Mr. Riley himself to explain the observed phenomena with any action of liquation. According to the theory of liquation the centre and tops of the ingots should be considerably harder than the outside; but what did the tests show? The very contrary. He would not, therefore, attempt to reconcile

Mr. Greenwood.

the results of compression with the opposite ones due to liquation; for liquation went on also in the pressed ingot. The exterior of the pressed ingot was throughout the tests stronger than the centre, and the greatest strength was at the top. Mr. Riley also professed, like others, to find from the Tables a greater degree of uniformity in the unpressed ingot. Mr. Greenwood had abstracted from Appendix VI the mean results from the lower two-thirds of the unpressed ingots and from the whole of the pressed ingot, and comparing these with reference to strength and ductility only, they were as under:—

	Unpressed Ingot		Pressed Ingot.	
	Strength in Tons	Elongation per cent	Strength in Tons	Elongation per cent
Mean of ingot	28·64	7·91	30·07	12·71
Mean of best section . .	30·91	12·44	32·63	16·55
Mean of worst section . .	22·91	2·02	26·98	10·13

The highest average ductility of the unpressed ingot was 12·44 per cent., and the lowest only 2·02 as against 16·55, the highest figure in the pressed ingot, and 10·13 the lowest. In the one case there was a difference of 600 per cent., and in the other a difference only of 50 per cent. between the highest and the lowest figures. Mr. Vickers accepted the statements that the occluded gases were evolved from the steel at the moment of its solidification; he also admitted that a head of metal (afterwards to be rejected) must be cast upon the ingot, in order that the lower portion should be solid. So far they ran on parallel lines, but then they diverged immediately. Mr. Vickers was "positive" that all escaping gases during compression proceeded from the lining of the mould. That statement he could only take to mean that Mr. Vickers had not seen the process, that he had not considered the volume, the nature, or the method of the evolution of the gases. Mr. Vickers had mentioned that in casting an ingot in an ordinary lined mould, there would be a considerable amount of gas escaping and burning. He was there comparing linings of 1 inch, 2, 3, and 4 inches thick in the ordinary mould, against a thickness of lining only ⅜ or ¼ inch in the mould for compression. If he prepared that mould (Fig. 3) properly and cast an ingot in it, he would see that there was no visible escape of gas from it. Therefore that part of his contention failed. Mr. Vickers and Colonel Dyer had described the action of

Mr. Greenwood. the presses in their own fashion, and shown how an outer solid casing was first formed enclosing an inner core of fluid metal, and Mr. Vickers had asked:—"Was it conceivable . . . that gases eliminated after the formation of this wall could be driven through it, and, above all, without leaving a trace of their passage." He thought he was going to startle Mr. Vickers, but the wind had been taken out of his sails in the course of the discussion. He had intended to meet the statement with an emphatic "Yes, it is possible to conceive that action," and he would remind Mr. Vickers of some experiments in which Professor Roberts-Austen, about the year 1881, described the escape of occluded hydrogen gas from heated metal. Gas, and especially hydrogen, could pass from, and through, heated iron into a vacuum, and if that was possible how much more was it possible for gas, and hydrogen in particular, to be eliminated from metal under pressures such as were here dealt with. But he by no means confined himself to that theory. He had stated distinctly (p. 114) that he doubted if any considerable amount of gas was evolved during compression at that stage, but, on the contrary, had surmised that in all probability the gases were then kept by the pressure in occlusion and not eliminated, or that if they were first eliminated they were re-occluded during the operation of the pressure. Professor Roberts-Austen had referred to the tempering of steel. He differed from the Professor entirely in his argument. "Temper" was a noun used by engineers and metallurgists to express a quality of the steel as cast, and the tempering of steel was applied to an operation performed upon the steel afterwards. The words, therefore, were not capable of much misconception, at any rate amongst steel-makers. Colonel Dyer had stated that the ingots cast at Manchester always had a great hole at about 14 or 16 inches from the top. If that were the case, he could only commend the Paper to their consideration as showing that such a thing was unnecessary. It did not occur at St. Petersburg, and it need not occur elsewhere. He had never said that good steel could be made out of chemically bad metal, and he had never thought it. He presumed that Mr. Vickers' allusion meant metal that was bad because of its chemical composition. Compression did nothing with the chemical constituents so far as he knew. If there was sulphur, phosphorus or silicon in the metal before compression, they would be in the metal afterwards, and would exercise the same influence upon the metal of either pressed or unpressed ingots. He made no pretence whatever to eliminate anything of that character. The process was simply designed for, and required to produce solidity and uniformity, and, as Colonel Dyer had remarked, to obtain a larger quantity of metal from every ingot for useful purposes. It was stated by Colonel Dyer and Mr. Cowper that fluid-pressed steel was never made with high carbon. That was erroneous. The Paper itself had given an example of steel containing 0·83 of carbon, and the production of such steel was a daily operation. Mr. Walker had said that sound ingots were daily made, and that the Paper had to go back eight years for a specimen of bad steel. By what process that date was arrived at he did not know. He could only refer to Mr. Vickers, Mr. Ellis, and others, who had said that large steel ingots were not so daily made. As to the examples cited in the Paper, they were not eight years, nor eight months, nor (many of them) eight days old when the Paper left his hands. The Paper was written in general terms, and the figures were filled in at the last moment from data only just completed. As to the evolution of "sulphur and other objectionable gases by lighting a fire on the top of the ingot" he would leave Mr. Walker to carry out for himself, since he was afraid that neither science nor facts would come to his assistance in supporting such a theory. Compressed steel had been compared to milk and to clay, but he did not think the comparisons were very happy. An example of the treatment of clay referred to by Sir R. Rawlinson was afforded in the every-day performance of treading wet clay during the manufacture of ordinary crucibles for the steel foundry. The cases were somewhat analogous. There was a certain amount of kneading, but the kneading was accompanied necessarily by a certain amount of pressure for the expulsion of atmospheric air from the clay. Mr. Davis had complained of a faulty cylinder supplied to him; knowing nothing of the details of its production, he would not attempt to defend it; but against an example of that sort he would quote Mr. Traill, who had stated that, in all the mechanical tests that he had seen of compressed steel, he had never come across an indifferent specimen. Mr. J. P. Spencer had remarked that, in his opinion, neither the strength nor the ductility of steel were dependent, as commonly supposed, upon the work put upon it. If this were so, then his arguments, as also those of others who had maintained that the fluid-pressed ingot was improved only to the extent of the forging it had received during compression, surely fell to the ground. Mr. Spencer had also stated that he could produce ingots which were sound, but the composition of such ingots was not stated. Mr. Greenwood suspected that such ingots would contain far too much silicon for the purposes to which special references had been made; and comparisons could not be made between such Mr. Greenwood.

Greenwood. metal and steel, which was practically free from silicon. The latter metal, after dead melting and the exercise of every precaution, had hitherto declined to yield sound ingots except under compression. The figures supplied by Mr. Spencer, obtained from a 4½-inch square ingot, were clearly not comparable with the tests of the Paper, which were taken from a 34·25-inch ingot. It had also been asked who was to decide the differences between the advocates of compression and of the ordinary methods. The answer came, he believed, from the steel user, for ever since the compressing plants had been at work a scarcity of work, paid for at high prices, had been unknown to them. Mr. McDonnell partially answered the theory of Colonel Dyer as to the action of the press in bending down the sides of the ingot, so as to produce a hole at the centre near the top; but neither speaker fully appreciated the fact that the pressure first came upon the metal whilst the metal was still fluid, and then continued to act uninterruptedly until perfect solidification had occurred, so that the formation and turning over of any solid wall in the manner suggested did not appear possible. Mr. McDonnell concluded that "if strength was wanted . . . the crystals should be very small," and the Author was not prepared to say that some of the phenomena and results of compression might not be due to such a cause; since under pressure not only was the crystallizing point deferred considerably, but the formation of large crystals was prevented, and the fracture of compressed steel ingots always presented a much finer crystalline structure than the same metal cooled under ordinary conditions. The advocate of jigging or hammering at the bottom of the ingots failed to appreciate the difference between sacks of grains of wheat and a rapidly solidifying mass of steel, the gases in which were possibly not evolved until the moment of solidification, after which jigging would be quite ineffective, as frequent trials had shown. He had seen many cracked ingots in various works, but not from pressed steel, and he had inquired from Russia if, during his absence, any cracked ingots had been reported from pressed ingots. The reply confirmed his own experience, that a cracked ingot after fluid compression was unknown in those works. He would also respectfully submit to Lord Armstrong whether this and the experiments of the late General Kalakoutsky, which showed that the internal stresses within a pressed ingot were exceedingly small, whilst those of an ordinary ingot were dangerously high, were not sufficient to warrant the conclusions of the Paper on this point. Properly pressed ingots did enjoy an immunity from these troublesome cracks. He was sorry that detailed chemical analyses were not made at the various sections of the ingots, but these were not commenced with the earlier experiments, and it became impossible to satisfactorily obtain them later on. However, he hoped to make good this defect, as also, by operating upon an ingot submitted to much higher pressures, to be able shortly to present results of what had been done under more favourable conditions than those selected for the Paper. Mr. Greenwood.

Correspondence.

Mr. J. O. ARNOLD remarked that the Paper must be regarded as of the highest interest and importance, filling up as it did a distinct gap in the literature of steel metallurgy. The cause of the absence of anything like complete chemical analyses of the steels upon which such thorough mechanical tests had been made, was sufficiently obvious and natural; but such an omission of course rendered the Paper incomplete. It was also a matter of regret that the internal molecular structure of the ingots could not be removed from the region of hypothesis by a series of photo-micrographs from properly prepared sections. It could not be too strongly urged, that full information concerning steel could only be obtained from a correlation of the chemical, mechanical, and microscopical tests yielded by the piece under examination. The importance of originally fairly sound ingots for forgings, was beyond question. Some years ago he had a painful experience with Bessemer tire ingots, upon which the waste was very large, and such chemical remedies as could be applied, were ineffectual. These ingots were, in some cases, so riddled with gas-bubbles, that their consignment to the scrap-heap was a necessity, the metal between the blow-holes cracking under the blows of the hammer into large roaks. An ingot was placed in a tank under hot, recently boiled water, and a special drill was made, to the shank of which a number of glass tubes full of water could be attached. On drilling into the ingots, an evolution of gas took place into the tubes. A eudiometric analysis of this gas revealed the fact that it was chiefly hydrogen, and the lime-water tests, applied before and after explosion with oxygen, gave negative results, thus indicating the absence of (or at any rate, the presence of, only a very small proportion of) oxide of carbon. It was interesting to note that the results of these experiments totally negatived an idea put forward some time ago, that the hydrogen obtained, resulted from a chemical decomposition of the water; because when the notes Mr. Arnold.

Mr. Arnold. made as to the quantity of gas evolved from each drill-hole, were compared with the ingot, it was found that the sides of the borings from which the largest quantities of gas were obtained, were full of blow-holes, whilst the sound borings gave off no gas. The excessive proportion of the occluded gases was ultimately satisfactorily removed by brisk mechanical agitation of the contents of the ladle before teeming the ingots. On pp. 130 and 131, the Author had given a series of tests of annealed shell-steel in its soft state, and of the same material from a hardened and tempered shell which had sustained firing impact on an armour-plate, and stated, that "the tests afford evidence of the molecular condition of a successful projectile after it has been fired at an armour-plate." It was, however, obvious that in the absence of the tests given by the same steel in an uncompressed condition, these results could not be taken as evidence of the superiority of the compressed material. Again, it was evident that the molecular changes which had taken place (namely, a large increase in the elastic limit and ultimate stress and reduction in the extension, both most marked at the apex of the shell), were to be attributed to the influence of hardening, and the molecular change, if any, due to the impact, remained an unknown quantity owing to the absence of an intermediate series of tests made on the shell steel after tempering and before firing. To the majority of the theories enunciated by the Author as to the blowing and piping of ingots, his experience led him to give a cordial support.

Mr. Firth. Mr. T. Firth thought it a pity there was such a wide difference in the temper of the two ingots taken for trial. The unpressed ingot having 0·50 per cent. of carbon, and the pressed ingot 0·39 per cent., there could scarcely be a comparison of value between them. He believed the tests would be in favour of the milder ingot. Also, it seemed hardly fair to compare one ingot just as cast with another which had been submitted to some work, the fluid compression apparently acting on the tests in the same direction as would a certain amount of forging or pressing after reheating. The tests, especially those nearer the outside, of the softer and pressed ingot, were acted on by this fluid compression, just as they would be if the ingot were reheated and forged, and raised to about the same tensile-strain as the harder and unpressed ingot. In a similar way the elongation would be improved to even a greater extent. The comparison would be better if the tests were taken after the same two ingots were reheated and forged, and it would be very interesting to know if this had been done. Allowing for the great difference in temper, he did not think the tests from the lower parts of the ingots would vary much. The extra cost of fluid compression would, no doubt, as the Author said, be more than compensated for by the larger piece of the ingot that could be used. Mr. Firth.

Mr. Hadfield. Mr. R. A. Hadfield observed that whatever might be the opinion held as regarded the process described, the preparation of the Paper must have involved very considerable care and trouble. The Author was the head of the rising technical school in Sheffield, and it was an especial satisfaction to Mr. Hadfield, as a Sheffield man, to think that so able an exponent of technical matters was in that position, and devoting himself to the promotion of technical education. It was difficult to understand how compression benefited steel, seeing the very high results that were now obtained both from forged steel and steel made in the ordinary way, and especially so in face of the recent interesting results of the cast-steel gun tests in America. The Standard Steel Casting Company of Thurlow, Pennsylvania, supplied a gun pure and simple, neither forged, hammered, nor oil-tempered, but simply annealed in the usual way; and in eight different test-bars cut from different parts of this casting, the mean elongation amounted to no less than 21 per cent., and the mean reduction in area to 32 per cent. It seemed doubtful whether either forged or compressed steel could have given better results. As regarded the effect of fluid compression upon steel, it would be interesting if the Author could add to the data what was the actual reduction in diameter between the size of the mould and that of the cast ingot when cold; that was what was the actual diameter of the mould when the steel was first run in, and what was the diameter of the ingot-casting itself when cold. Seeing that the Author mentioned that the compression process caused an average reduction in length of 1½ inch to the foot, it would be well to know whether this process in any way interfered with the ordinary contraction of steel, which was, as was generally known, ¼ inch per foot, or double that of cast-iron. It had been mentioned in an American Paper that Mr. Hinsdale, of the Jersey City Steel Works, had experimented in compressing a small 3½-inch square ingot with a pressure of 65,000 lbs. per square inch, and he stated this was nearly double the pressure ever applied by Sir Joseph Whitworth. The result was the shortening of the ingot from 25 inches to 22 inches in length, and perfect solidity was obtained except that the pipe appeared in the same form, a flaw, as it ordinarily displayed itself at the forged end of a bar. Mr. Hinsdale thus found that piping or its effects could not be eliminated by pressure, and invented a perforated plug to insert in the mould upon the top of the fluid metal, through the

Mr. Hadfield. perforations in which the gases might escape when applying the pressure. With reference to the actual effect of compression on the fluid gases in steel, it was very difficult to offer an opinion without further data, but without doubt, in certain kinds of steel, the action mentioned by the Author did take place, namely, at a particular point when solidification had nearly occurred, certain gases were given off. Dr. Muller had very thoroughly investigated this question.[1] It would have seemed desirable to have more chemical data respecting the steel treated in the examples given by the Author, and especially as to whether compression stopped the liquation of sulphur and phosphorus, a fact of late much dwelt upon by leading metallurgists; also if drillings had been taken from an ingot in the way shown by Mr. T. E. Vickers with uncompressed steel. Mr. Walrand, a Continental metallurgist, had stated, in 1885, in an article on the Structure of Steel Ingots, that even compressed ingots which did not show any apparent trace of pipe would do so after polishing and etching with acid. Had the Author made any experiments as to this point? In conclusion, it was difficult to offer any definite opinion as to the effects of fluid compression upon the quality of steel, without having the corresponding tests on forged specimens from the same steel. No doubt the Author's idea, and very properly so, was to narrow down and to confine the discussion if possible to one class of material, namely, steel in its unannealed cast state. But, as founders of all metals well knew, the irregularity of any cast material, and especially steel in its cast and unannealed state, rendered it difficult to draw therefrom definite and satisfactory conclusions, as such material was seldom, if ever, used without further treatment. No report as to any kind of steel could be well considered complete without tests of it, not only in its cast, but also in its annealed and forged states. The excellent material now being produced in Sheffield by such firms as Messrs. Vickers, Brown, Cammell, Firth and others, without the application of any fluid-compression process, and merely by a judicious selection of materials, and by the application of proper means of melting and working the steel, seemed the best proof that fluid compression was not necessarily requisite for the production of homogeneous and reliable steel.

Mr. Howe. Mr. HENRY M. HOWE, of Boston, U.S., observed that in the Whitworth steel-compressing process two periods might be distinguished, compression during liquidity and compression during the subsequent solidification and plasticity, or into

---

[1] Minutes of Proceedings Inst. C.E. vol. lxi. p. 360.

Mr. Howe. "liquid compression" and "plastic compression." On *à priori* grounds little could be expected from liquid compression, further than the bottling-up of gas within the metal, to be evolved later during solidification. Molten steel was practically incompressible. Its solvent power for gases, like that of other liquids, increased with the existing pressure. Pressure applied before the steel solidified, then, should retard or even wholly arrest the escape of gas from the surface of the molten metal, which usually occurred, and should therefore increase the amount of gas which was retained, to be evolved later during the solidification of the metal; for the solvent power of steel, as of other substances, for gases diminished enormously during solidification. The escape of gas from the metal before solidification was harmless; the escape of gas during solidification, however, led to the formation of blow-holes, cavities due to gas which formed within the metal while it was still so soft that the particles of gas could collect into bubbles, but not so soft that these bubbles could rise quite to the surface and escape. Compression during plasticity, however, should restrain the formation of blow-holes by squeezing out the gas which formed, just as water was squeezed out of a sponge, by diminishing the size of the gas-bubbles which were not squeezed out, and by increasing the solvent power of the metal for gas. In short, liquid compression appeared wrong in principle, plastic compression appeared right. But as the outer layers solidified while the inner ones were still liquid, it might be hard to apply plastic compression without more or less liquid compression. Now apprehensions had been felt that the effect of plastic compression, in limiting the formation of blow-holes, and in closing the central contraction-cavity or pipe, might not greatly outweigh the bottling-up effect of the preceding liquid compression, and the increased evolution of gas during solidification to which that bottling-up should lead; and that the net effect of the two operations might not lead to much greater solidity than that obtained without compression. The Author's statement that liquid-compressed ingots, 34·25 inches in diameter, when parted in two lengthwise, were found perfectly solid, was certainly reassuring, and extremely welcome. But the important question connected with liquid compression, whether liquid-compressed steel was better than other steel, was left just where it had been found by the Author. True, some 30 per cent. of the weight of uncompressed ingots might have to be rejected on account of cavities. But though rejected, the steel was not lost; it had merely to be remelted and recast, at a cost which, in the opinion of many,

Mr. Howe. was far too small to warrant the erection of liquid-compressing machinery. The Author indeed showed what had been generally known for many years, that the physical properties of compressed ingots were far better than those of wholly untreated ingots; but nobody would think of using steel ingots or other steel castings for any important purpose without some form of treatment, either by forging or by heat. All steel-makers knew the comparative worthlessness of untreated castings, and the enormous benefit to their physical properties which could be readily conferred, either by reheating them to the critical point *b* of Chernoff (W of Brinnell), or by forging. It was evident that plastic compression was a form of forging, and that it should break up the coarse crystalline structure of ingots like other kinds of forging. The defects of steel castings were two: cavities, and coarsely crystalline structure. The former could be obliterated by forging under sufficiently powerful apparatus; the latter either by forging or simple treatment by heat. The question was.—Could they, and the weakness and brittleness which they caused, be removed more completely by compression during and immediately after solidification, than by forging the solidified metal? Now, to settle the question whether liquid compression was expedient, evidence was wanted, not as to the already-known grave defects of untreated castings, which nobody used; but whether those which were used—to wit, forgings and heat-treated castings—were better for having undergone liquid compression before being forged or treated by heat. He had endeavoured to throw some light on this question by comparing the physical properties of the best forgings which had been publicly described, and which had not undergone liquid compression, with the published properties of Whitworth compressed steel, seeking from the management of the Whitworth establishment the properties of its best products. He reasoned that, if Whitworth compressed steel was no better than what was made by others without compression, there would be little ground to think that liquid compression, which was believed to be extremely costly, really accomplished any useful result. According to this comparison, the properties of Whitworth compressed steel, while admirable, were no better than those of the best uncompressed steel of several American establishments.[1] Nor did he

---

[1] "Engineering and Mining Journal," August 4 and 11, 1888, pp. 87, 88, 110. Also "The Metallurgy of Steel," vol i, pp 159 to 161, now in the press

The comparison was made by plotting in one diagram tensile-strength as ordinate and elongation as abscissa, and in another diagram elastic limit as ordinate and elongation as abscissa. In both diagrams a sort of milky way was

Mr. Howe.

find that the physical properties of compressed steel, which the Author gave, and which he had plotted on these same diagrams, excelled those of the best uncompressed steel in America. He must except the properties of the steel shell after firing against an armour-plate, which by this operation had become most remarkable. It might, however, be questioned whether they were comparable with those of steel under the usual conditions, since their excellence seemed to have been acquired on firing; the same metal in its soft state appeared to be only fairly good. The commendations of Whitworth steel by General Maitland and others, and the general public knowledge and experience cited by the Author, were far from convincing. It was generally understood that Whitworth steel was admirable; but it had not yet been shown that the uncompressed steel of Krupp and of Schneider in Europe, and of the Cambria and the Otis works in America, was inferior to Whitworth's.

Admiral Kolokoltzoff.

Admiral KOLOKOLTZOFF, I.R.N., observed that at the Abouchoff Works no cavity was ever found in the extreme top of the compressed ingot. If the pressure had not been sufficient, or if the ingot was large, some cavities of very small volume might occur in the centre of the ingot from one-fourth to one-third of its length from the top. There had never been occasion to cut off any portion; in fact it was considered that the top of the ingot was the best part of it. Although the size of the columns, and the largest amount of pressure (10,000 tons) that might be applied was stated correctly in the Paper, such pressure was never used, because it had been found from practice that one-half of it, or even one-third, was quite sufficient.

Mr. Thwaite

Mr. B. H. THWAITE remarked that when an ingot mould was filled with molten metal, the latter occupied a cubic space greater than it would do in its cold condition, if solidified so as to produce perfect molecular contact, in the ratio $X^3 \times B : X^3$, where X represented the size of the ingot, and B the dilation due to the difference of temperature between the temperature of solidification and that of fusion. In the ordinary system of casting ingots, this perfect solidification was impossible; the ingot was cooled on the

---

thus formed, but, with a solitary exception, the spots for Whitworth compressed steel lay within the band, undistinguishable from the uncompressed steel of the best American makers. Admitting that this method was not conclusive, since the tensile-testing-machine gave but a rough measure of the absolute value of the metal, it certainly seemed very probable that, if liquid compression really benefited the metal greatly, its results would have been apparent in these diagrams.

Mr. Thwaite. outer sides whilst its internal condition was molten; the result was that the outside became, on cooling, a comparatively rigid shell, of nearly the dimensions of the metal in its molten and dilated condition, having in its interior metal in a still molten condition. When the latter cooled down, the interior of the ingot was filled with cavities having a total cubic capacity, represented by the different space that the metal would occupy if solidified in perfect molecular contact, and what it occupied in its molten condition, these cavities preventing molecular contact. A fairly accurate estimate of the relative volume of these cavities could be arrived at. Taking for an example an ingot 45·72 centimetres square, by 152·4 centimetres long, having a cubic capacity of 6,967 cubic centimetres, with the dilatability X in the following formula, $X = A + A' (T - 40)$, where T was the temperature, A the coefficient of dilatability at 40° Centigrade, and A' a coefficient fixed by Fizeau (Annuaire du Bureau des Longitudes 1885). Then the volume of cavities that would be produced if the ingot was chilled initially on its outside, whilst the internal metal was molten, would be equal to 22 cubic centimetres. These cavities distributed throughout the ingot might be reduced in volume by hydraulic compression. But if the metal was cooled on the outside surface before the inside was cooled, would hydraulic compression produce absolute molecular contact? Unless the metal cooled from one side or from the centre it was hardly possible to conceive that the cavities, due purely to the imperfectly uniform molecular contraction, could be prevented. If the metal was of a uniform character and cooled in such a way as to effect molecular contact, the specific gravity would be uniformly fixed. The average specific gravity of compressed steel given in the Paper agreed very closely with that, which might be expected from calculation, and taking an ingot of a volume equal to 6,967 cubic centimetres and assuming it were cooled, so that the 22 cubic centimetres due to outside cooling were eliminated by cooling from one side or from the centre, then $\left(\frac{22}{6{,}967} \times 0 \cdot 78542\right) + 0 \cdot 78542 = 0 \cdot 787912$. This was very near the average specific gravity given by the Author as 0·78795. In the calculation the specific gravity of ingot steel cast in the ordinary way was taken as 0·78542. The pipings and cavities produced by the outside cooling on the present system involved a most serious thermic waste. If only 2 cwt. of porous metal were cut from the ends of a 10-cwt. ingot, this represented a loss of 3,000,000 thermic units Fahrenheit, a great part of which, by the application of some system of producing natural and perfect molecular contact, during the cooling of the metal, could be saved. The uncertainty of steel as to its uniform structural reliability was due to the distinctive laminations and cavities rolled down in the ingot, which could only be discovered by drilling the entire surface of the plate. Mr. Thwaite.

Mr. W. H. Greenwood, in reply to the correspondence, said there was little that had not been referred to during the discussion, or called for further comment. In the statement that "he did not think the tests from the lower parts of the ingots would vary much," Mr. Firth practically accepted the contention of the Paper, for he obviously assumed that the lower part of the ordinary ingot would be the best portion, because it would be sound and cast under the pressure of the head of metal above; but it was claimed for fluid compression, and shown by the tests, that compression rendered the top and whole of the ingot at least equal to the lower part, or to the best portions of the unpressed ingot. Admiral Kolokoltzoff even stated that the top of the pressed ingot was considered the best. He was afraid Mr. Hadfield's satisfaction with the cast-steel guns manufactured in America, one of which broke up under proof, while the other one had not yet so succumbed, would not be endorsed by artillerists and steel-makers generally, as satisfactory evidence of the suitability of steel castings for guns at the present time. He did not know why fluid compression should materially interfere with the operation of the ordinary law of contraction for sound steel ingots; and the enquiry as to dimensions of the ingot before and after compression appeared to be furnished by the statement on p. 86 of the Paper, where the difference in volume between the pressed and unpressed ingots was stated to range between 8 and 12 per cent., the contraction in length being given as usually 1½ inch to the foot, and it sometimes exceeded that amount. With respect to the quoted experiments of Mr. Hinsdale upon a 3½-inch square ingot, such experiments had invariably proved failures. The earlier experiments, conducted upon 4, 6 and 8-inch ingots in this country, had shown similar results, namely, that the mass of metal so operated upon was altogether too small for fluid compression. The metal, in such cases, solidified far too rapidly for the successful application of fluid compression. The pressure applied to such small masses effected only a breaking down of the structure of the steel; just as occurred with larger masses when the pressure was applied after considerable delay, when a partial solidification of the metal might have already taken place. Drillings had been taken over the surfaces of horizontal sections of compressed ingots, and liquation of sulphur and phosphorus towards the centre was found to take place. Mr. Greenwood.

Mr. Greenwood. Mr. Howe divided the action of the press into two stages, "liquid," and "plastic compression," the former of which he concluded was wrong, and the latter right. His argument, however, seemed to falsify such a position, for he stated that the escape of gases, and so the formation of blow-holes, was retarded, or even wholly arrested, by high pressures applied during the liquid stage. The Author concluded that unsoundness would therefore not result during that stage. Mr. Howe further considered that, during the plastic state of the metal, the press "should restrain the formation of blow-holes by squeezing out the gas," a theory generally opposed during the discussion, and only very partially accepted by the Author; nevertheless, from such statements, it would appear to follow that a continuous pressure applied throughout both the liquid and plastic stages would yield ingots of perfect solidity; however, Mr. Howe did not consider the saving thus effected, which amounted to some 30 per cent. of the metal cast, as of much importance, since such rejected metal "had merely to be remelted and recast." But the first cost of melting 30 per cent. too much metal, and then of preparing the same for the furnace, and remelting these large masses of rejected steel (10 tons and upwards from a 40-ton ingot), was not the small item suggested; while furnaces, cranes, and tackle had each to be provided of the higher power and capacity required for the manipulation of masses of steel 30 per cent. heavier than they need be were fluid compression adopted. Statements of the superiority of this or that maker's steel, American or European, over others, required always to be received with caution, especially when the whole history of the samples was not known, for the quality of a steel was obviously variable, according to the method of manufacture, the raw materials employed, and by subsequent heat treatment; also the conclusions might be affected by the method of testing. Before the value of any particular treatment could be determined, it appeared necessary that comparisons should be made upon samples identical in all respects except as to such treatment. The effect of fluid compression was considered in the Paper, by examining practically the same material when pressed and when unpressed, and showed that the process produced sound ingots of mild steel, free from cracks or tears, and any portion of which was equal or superior in physical character to the corresponding portion of the unpressed and always unsound ingot. The results of treatment by heat, and of forging upon such compressed metal were equally satisfactory; but data for the comparison were not yet in the possession of the public, such data as Mr. Howe referred to being illusory, every detail, both as to method

Mr. Greenwood of production and of treatment of the samples, being probably different with each set of specimens to which he referred. The remarks of Mr. Thwaite had reference to contraction cavities only, and his calculations and reasoning would appear to confirm the Paper as to the elimination of blow-holes from the steel. But, he asked, would hydraulic compression produce absolute molecular contact if the metal was cooled on the outside surface before the inside was cooled? To this he would answer that, under the conditions of cooling in the special mould employed, the pressure, when properly applied and sufficiently prolonged, did assure such contact, so far as could be revealed by mechanical testing of the metal and examination by the microscope.

14 May, 1889.

Sir GEORGE B. BRUCE, President,
in the Chair.

The discussion on the Paper by Mr. W. H. Greenwood, on "The Treatment of Steel by Hydraulic Pressure," was continued throughout the evening.

21 May, 1889.

Sir GEORGE B. BRUCE, President,
in the Chair.

Death of Mr. Francis Croughton Stileman, Member of Council.

Sir G. B. Bruce. The President said, It is my painful duty to intimate from this Chair the death of an esteemed Member of Council, Mr. Frank Stileman. Last Tuesday Mr. Stileman was present in his usual health, which in later years had never been very robust. On Saturday last he was struck down as in a moment. Natural modesty, combined with delicacy of constitution, prevented Mr. Stileman from ever taking a very prominent public part in our discussions; yet in spite of that his fellow-members discerned those qualities of heart and life which led them to elect him again and again to a seat on the Council. Those who met him at the council-table could heartily endorse the wisdom of placing him there, and now mourned the Providence which had deprived them of his companionship. We gladly place on record the high esteem in which we held Mr. Frank Stileman, believing that he

G. B. ace. maintained in his professional and personal character those qualities which have secured to our profession and to this Institution the confidence which the world had so fully accorded. May the Institution ever have amongst its leaders men as able, as single-hearted, and as true as Frank Stileman.

The following Associate Members have been transferred to the class of

Members.

Humphrey Chamberlain.
David Morris.
Alfred Eley Preston.
Henry Badeley Smith.

The following Candidates have been admitted as

Students.

John Henry Barker.
William Edward Gilbert Belcher.
Hilaire Belloe.
Peter Clarke.
James Stanhope Cockburn.
Samuel Edward Cooper.
Richard John Cracknell.
William Joseph Bremner Davis.
Sholto Hyde Whyte Douglas.
William Piercy Edwards, R.N.
Bernard Morley Fletcher.
Frank Laurens.
John George Liversidge, R N.
John May.
Henry Arthur Fitzherbert Musgrave.
Harold Stanley Percival.
John Smith, Wh Sc.
John Cuthbert Traill, B A.
Edward Vernon Waud.
Henry Richard Kemp Woodward.

The following Candidates were balloted for and duly elected as

Honorary Members.

Sir Henry Bessemer, F R S.
Sir William Thomson, LL.D., F.R.SS. L. & E

Associate Members.

William Thomas Clifford Beckett.
John Watkins Brough, Stud. Inst. C.E.
William Samuel Child.
Stephen Butler Cottrell, Stud. Inst. C.E.
Alfred Fawcus, Stud. Inst. C.E.
Charles Henry Gale, Stud. Inst. C.E.
George Hewson.
Reginald John Jones.
William Turner MacLellan, Stud. Inst. C E.
James Marchbanks.
Lewis Prichard Moline.
David Oldfield.
Norman Scorgie.
John Harris Hazlett Swiney, B.A., B E.
Arthur Pepys Wood.
John Woodside, Stud. Inst. C.E.
Robert George Young.

The discussion on the Paper by Mr. W. H. Greenwood, on "The Treatment of Steel by Hydraulic Pressure," occupied the whole evening.

ANNUAL GENERAL MEETING.

28 May, 1889.

Sir GEORGE B. BRUCE, President,
in the chair.

The Minutes of the Annual General Meeting of the 29th of May, 1888, were read and confirmed.

The Notice convening the present Meeting having also been read, it was moved, seconded, and resolved,—That Messrs. R. W. Peregrine Birch, George Chatterton, H. W. Chubb, C. H. Cooper, F. S. Courtney, W. Santo Crimp, W. Fox, Alfred Fyson, R. F. Grantham, Killingworth Hedges, G. M. Lawford, Wilfrid Stokes, and J. M. Wood, be requested to act as Scrutineers for the election of a President, of four Vice-Presidents, and of fifteen Other Members of Council for the ensuing year; and that, in order to facilitate their labours, the Balloting-papers be removed for examination at intervals during the hour for which the ballot remained open.

The Ballot having been declared open, the Secretary read the Report of the Council upon the Proceedings of the Institution during the Session 1888–89 (p. 207), the Statement of Accounts being taken as read.

Resolved,—That the Report of the Council be received and approved, and that it be printed in the "Minutes of Proceedings."

Resolved,—That the best thanks of the members be tendered to the Vice-Presidents and the other Members of Council for their successful endeavours to promote in every way the efficiency of the Institution.

Sir John Coode, K.C.M.G., the senior Vice-President, replied on behalf of himself and his colleagues.

The Ballot was then declared to be closed, having been open more than one hour.

Resolved unanimously,—That the cordial thanks of the Institution be given to Sir George B. Bruce, the President, for the very able manner in which he had performed the duties of his office.

Sir George B. Bruce, President, expressed his thanks for the flattering terms in which the Resolution had been proposed and seconded, and for the cordial way in which it had been received.

Resolved,—That the thanks of the Institution by presented t Messrs. Rob. W. Graham and Alex. McKerrow, the Auditors, fo the Statement of Accounts which they had submitted; and tha Messrs. Alex. McKerrow and Robert White be requested to act a Auditors for the ensuing year.

Resolved,—That the thanks of this meeting be given to Dr. Pole, Honorary Secretary, to Mr. Forrest, Secretary, and to the members of the staff, for the able and energetic manner in which they had discharged their respective duties.

Dr. Pole and Mr. Forrest returned thanks.

The Scrutineers then announced that the following gentlemen had been duly elected:

President.

Sir JOHN COODE, K.C.M.G.

Vice-Presidents.

George Berkley.
Harrison Hayter.
Alfred Giles, M.P.
Sir Robert Rawlinson, K.C.B.

Other Members of Council.

William Anderson, of Erith.
Benjamin Baker.
John Wolfe Barry.
Edward Alfred Cowper.
Sir James Nicholas Douglass, F.R.S.
Sir Douglas Fox.
J. Clarke Hawkshaw, M.A.
Charles Hawksley.
Sir Bradford Leslie, K.C.I.E.
George Fosbery Lyster.
James Mansergh.
William Henry Preece, F.R.S.
Sir Edward James Reed, K.C.B. F.R.S., M.P.
William Shelford.
Francis William Webb.

Resolved,—That the thanks of the meeting be given to th Scrutineers, and that the Ballot-Papers be destroyed.

REPORT OF THE COUNCIL, SESSION 1888–89.

THE Council in resigning the trust committed to its charge has again to report a year of progress and prosperity for the Institution.

CONSTITUTION.

The Council has ever kept in view the main principle, often urged in former reports, that the name "The Institution of Civil Engineers" does not imply limitation to any particular class of practitioners; that the word "Civil," so frequently misunderstood and misused, means simply "civilian," as contrasted with a member of the military profession. Hence any person who follows the Art mentioned in the Charter of "directing the Great Sources of Power in Nature for the use and convenience of man," whether he be a Mechanical Engineer, an Electrical Engineer, a Municipal Engineer, a Mining Engineer, or an engineer of any other denomination, provided only that he be a "civilian," is eligible for admission, if qualified, into The Institution.

The Council has always acted on this broad basis, a basis which, by reason of the nature and constant extension of engineering work, is widening every day. It recognises the advantage of subsidiary engineering societies, which, indeed, are a necessary result of the division of labour in the profession, and of the magnitude of each of its branches. The Institution freely welcomes these societies, and accords to them every available facility. The Council, on this principle, has been in the habit of lending the Meeting Room to the Mechanical Engineers, the Electrical Engineers, the Iron and Steel Institute, the Municipal and Sanitary Engineers, and the Gas Institute, as well as to some other bodies engaged in scientific pursuits allied to engineering, such as, for instance, the Meteorological Society.

There is work for all the subsidiary societies named, in addition to that done by this Institution; but the Council hopes the day is not far distant when these societies, still keeping each its special individual existence, may become united in one great fold, worthy of the profession to which they all belong, but whose characteristic and comprehensive name belongs to this Institution alone.

The Council does not, however, wish it to be understood that, although the scope of the Institution is so wide, the admission to its privileges is unduly lax. The Council has not hitherto seen the way to establish (as some professional societies have done) an examination for admission; but it supplies the absence of this by a rigid inquiry into the qualifications of all candidates; and, in proportion as the applications become more numerous, so the necessity for this strictness becomes more imperative.

The Council most earnestly asks the aid of the members to render this task more easy. It is known that in some cases signatures have been given when the giver has in fact had a very limited personal knowledge of the candidate; but every member should recollect that his name, attached to a proposition-paper or to a transfer-paper, is tantamount to his certificate of the candidate's eligibility for the privilege sought, and, indeed, is, to a certain extent, an attestation of the truth of the statements made on the face of the application. It has sometimes happened (though rarely) that these statements have neither been borne out on inquiry, nor conveyed a meaning altogether consistent with fact. The Council is justified in dealing severely with such cases, and thinks that much of the responsibility should fall on those who have too lightly endorsed the statements.

With regard to the Student class, the Council has exercised its right to act somewhat more freely than with the Corporate Members. It is only consistent with the scientific character of the profession that every candidate for admission thereto should be required to undergo a fair preparation by pupilage; and the Council has now laid down a rule that no person shall be admitted as a Student unless he can also produce sufficient evidence of a competent knowledge of certain elementary subjects of general education; namely:—

English Grammar and Composition;
Elements of Mathematics;
Elementary Mechanics of solids and fluids; and
Two optional subjects of general literary or scientific culture.

These acquirements, it must be admitted, form only a small part of the theoretical training which every modern engineering student ought to receive; but the Council desires to enforce, as far as practicable, its opinion that a good general education, combined with an elementary knowledge of the special subjects required in the pursuit of the profession, is a preliminary necessity of the present time for the engineering student.

COMPOSITION OF THE COUNCIL.

One of the most important duties of the Council is the nomination of suitable persons for the various offices in the Council—in fact, the composition of its own body—in order that it may be not only efficient in its government of the vast interests committed to its care, but may be faithfully constituted as representing the free choice of the members of the Institution.

It was in the year 1878 that the present constitution of the Council, consisting of a President, four Vice Presidents, and fifteen ordinary Members (the full number prescribed by the Charter), was first adopted.

The Charter provides that the election of this body shall be left to the free and uncontrolled choice of the Corporate Members at the General Meetings.

Experience, however, has shown that it would be very unwise to risk the many chances of accident which might arise if the electors were left entirely unguided; it has therefore become the custom in all well-managed Institutions for the governing body to offer some help in the shape of recommendations of persons whom it considers properly qualified and fit for such responsible duties.

Therefore a By-Law (Section VI, Clause 2) was passed, directing the Council to submit a Balloting List of at least twenty-nine Members so qualified, stating which among them it recommends as President and Vice Presidents.

This list gives a choice of nine names more than can be elected, and it must be further borne in mind that the electors have liberty to substitute any other names for those suggested. But it has never happened that any Member has been elected whose name has not been included in the Balloting List prepared by the Council. The Balloting List having thus been so loyally received, the Council has felt it a duty to take great care in its preparation, and during the Session now terminating there has been a motive for even more than usual attention to this duty.

Shortly before the General Election of May, 1888, there was reason to think that a feeling existed in the body of the Institution in favour of a more rapid change in the Council, and in circulating the Balloting List for that election, the Council accompanied it by the following note:—

> "In issuing the Balloting List on this occasion, the Council thinks it right to convey to the members a notice of its intention to recommend to the consideration of the in-coming Council that a course may be adopted whereby a somewhat more rapid circulation in the Council may be ensured in the future than has hitherto prevailed."

Accordingly, the present Council has given the matter lengthened and anxious consideration; but the subject is beset with so many difficulties that the Council has been unable to take any decided steps in the matter, and can only offer to the members some general remarks.

In the first place, there has been great difficulty in determining to what extent there exists a desire for change. No formal representations to such an effect have ever been put forward, nor in any of the later General Meetings have any statements been made with this tendency. In the year 1880 a desire was expressed that greater choice should be given in the names submitted, and this was acceded to by the adoption of the present By-law, giving, as already stated, nine names more than were required. This would appear to have met the want then expressed.

The duration of the Presidentship, according to the By-law quoted, is limited to two years; but in the Report for 1880 the Council alluded to the existence of a general feeling that it would be desirable in future for a President to hold office for one year only. Since that time, Mr. W. H. Barlow, Mr. James Abernethy, Lord Armstrong, Sir James Brunlees, Sir Joseph Bazalgette, and Mr. Edward Woods have held the office for one year only; but Sir Frederick Bramwell, by reason of the alteration in the time of election, held office for two sessions, and Sir George B. Bruce was elected a second time.

When a promotion to the Presidency takes place, a vacancy is created for a Vice President, and in this case the Council holds it to be its duty to nominate that ordinary Member of Council whom it may, by ballot, determine to be the best fitted for the office. And when once a member has been elected Vice President, it is reasonable that he should continue to be nominated for that office until he arrives at the Chair.

It follows, therefore, from this statement that the only way in which it would be possible to obtain a more rapid change would be by the retirement of some of the fifteen "other Members of Council." The Council has earnestly considered how this could be arranged, and has discussed several schemes for the purpose.

The most obvious mode would be compulsory retirement by seniority of service. But this would have the manifest disadvantage that when a Member had most completely proved his efficiency and good qualifications, he would be obliged to retire, and would no longer be available as a Vice President or President, although he might be a most suitable person for either office. It has been proposed that Members so retiring should be eligible for re-election after a short interval; but such a provision would, to a certain extent, interfere with the object said to be desired, namely the more frequent introduction of new Members.

Again, it has been proposed that the principle for the retirement should be based on the comparative infrequency of attendance at the Council meetings; but this also would be unsatisfactory, as often the best men, from unavoidable business engagements, and other causes beyond their control, would be lost to the body.

For these reasons the Council does not see its way to propose any change.

In the Balloting List, Sir John Coode, the senior Vice President, is nominated for President, and the Council has selected Sir Robert Rawlinson, K.C.B., to fill the vacancy in the list of Vice Presidents.

From the list of ordinary Members two of the most honoured names are absent, those of Sir Henry Bessemer and of Sir William Thomson, who have found it impossible to attend the meetings. As a testimony of respect to these gentlemen, they have, on the recommendation of the Council, been elected Honorary Members.

The withdrawal of these two names leads the Council to suggest whether it might not be desirable to establish a rank of "Honorary Councillor," to which might belong not only all Past Presidents, but also any Vice Presidents, or other members who have served for a certain time on the Council, but who have from any cause ceased to belong to it. These persons might have the privilege of attending the Council meetings, thus giving the Institution the benefit of their advice or assistance; they would not, however, belong to the Council proper, and would therefore have no vote. It is not improbable that the establishment of such a class might occasion some voluntary retirements among Members of Council, and might therefore produce some increase in the rapidity of circulation in the most unobjectionable way.

The Balloting List contains the names of such of the present Members of Council as are eligible for re-election, and of twelve other Members of the Institution.

The Council is of opinion that the introduction of so many names as nine beyond the number to be elected is not working satisfactorily. The result of the arrangement might be to split up the votes to such an extent as to cause the choice to fall upon persons the votes for whom do not amount in number to a majority of the voters present.

THE PRESIDENT.

A gratifying recognition of the status of this Institution was received in a notification from the Prime Minister that the Queen

had been pleased to confer the honour of knighthood upon the holder of the presidential office at the time of Her Majesty's Jubilee. Answering Lord Salisbury's intimation, Sir George Bruce acknowledged, both personally and on behalf of the Institution, his sense of the distinction thus conferred.

THE ROLL OF THE INSTITUTION.

The number of members of all classes—Students excepted—on the Roll of the Institution on the 31st of March last was 4,739, being 183 more than on the same date in the previous year, or an increase at the rate of 4 per cent per annum. The additions to the Roll were caused by the election of 1 Honorary Member (H.R.H. Prince Albert Victor of Wales), 42 Members, 245 Associate Members, and 12 Associates. Among the 117 names which have disappeared from the list the Council regrets to notice the loss by death of two Honorary Members—Rudolph Clausius and Viscount Eversley—and of many old and respected members of the Institution.[1]

---

[1] The changes are as under for the Sessions 1887–88 and 1888–89:—

—	April 1, 1887 to March 31, 1888						April 1, 1888 to March 31, 1889					
	Honorary Members	Members	Associate Members	Associates	Totals		Honorary Members	Members	Associate Members	Associates	Totals	
Numbers at commencement	20	1,568	2,275	484		4,347	20	1,617	2,458	461		4,556
Transferred to Members			42	1					45			
Do. to Associate Members				3								
Elections		44	267	10	323		1	42	245	12	300	
Restored to Register				2								
Associate elected Member				..						1		
Deaths		30	25	20			2	42	23	13	−117	
Resignations		5	8	7	−114			2	12	7		
Erased		3	12	4	——	209		3	10	2	——	183
Numbers at termination	20	1,617	2,458	461		4,556	19	1,657	2,613	450		4,739

ADMISSION OF STUDENTS.

To the enforcement by the Council of the regulation as to the admission of Students, referred to in the Report of last year, is due the fact that the increase in that class was 15 only, as against 25 during the previous twelve months, the number on the 31st of March, 1889, being 989. The admissions during the year numbered 209, the name of 1 student was restored, while 82 were elected Associate Members, and 113 disappeared from the list. The Council feels satisfied that, although this class may not increase in numbers at the same rate as in previous years, the

The Deceases have been :—

Honorary Members :—Rudolph Julius Emanuel Clausius; and *Viscount* Eversley, G.C.B., D.C.L.

Members :—Frederic Foster La Trobe Bateman; Wilson Bell; *Sir* Charles Tilston Bright; John Brown (*Birmingham*); William Armitage Brown; Henry Carr; Thomas Russell Crampton; Richard George Coke; Robert Denny; Frederick Lewis Dibblee; James Easton; Barnard William Farey; John Fowler; William Francis; Frank Alexander Brown Geneste; Peter Greek; Edwin James Grice; Thomas Hack; Arthur Samuel Hamand; Thomas Hindmarsh; Victorino Aurelio Lastarria; Frederick Leslie; *Hon* Henry Haworth Leslie; John McConnochie; Charles Markham; Daniel Miller; James Muir; Frederic Murton; William Parkes; Julius Pazzani; Richard Peacock, M.P.; George Henry Phipps; Arthur Potts; Wellington Purdon; George Hennet Ross; Frank Salter, B.Sc., Wh.Sc.; Bernhard Schmidt; Frederic Cook Stephens; Thomas Summers; Richard Townshend; George Turnbull; and Benjamin Frederick Wright.

Associate Members :—William Batten; Ranson Colecome Batterbee; Alexander Cunningham Boothby; William Milner Crowe; Jonathan Sparrow Crowley; Charles Dick; James John Alexander Flower; Samuel Harpur; Charles Lorimer Hensman; Charles George Kleberg, Ernest Frederic Morant; John Pagan; William Alfred Harry de Pape; Alfred Phillips; Robert Pinchin; Peter Roberts; John Burn Anstis du Sautoy; Charles Thomas Spencer; John Trickett; Barrow Turner; George Reaveley Tyndall; John Wakeford; and Herbert Francis Waring.

Associates :—John Ashworth; *Captain* Augustus Samuel William Connor, B.S.C.; George Hawkins; Graham Hewitt Hills; *Sir* Henry Arthur Hunt, C.B.; Henry Lee; John Phenuel Roe; George Naylor Vickers; William Wakeford; *Colonel* David Ward, R.E.; *Captain* Harry Borlase Willock, R.E.; Hugh Wilson; and John Oliver York.

The Resignations were :—

Members :—Albert Chesterfield Jenour; and William Colton Parker.

Associate Members :—Edwin Clerk Allam; William Robert Barker; Henry Ogle Bell-Irving; John Clark; Robert Dempster, Sen.; Arthur Hicks; Charles Edward Mackintosh; Alfred Marshall, M.A.; Leander Munro Miller; Francis Preston; John Nidd Smith; and Thomas Sunderland.

Associates :—Edward Norton Clifton; *Colonel* George Chancellor Collyer, R.E.; Louis John Crossley; *Colonel* Frederick George Hankin, M.S.C.; *Colonel* William Coles Phillpotts, R.E.; William Spence; and Samuel Leith Tomkins.

Institution cannot but benefit ultimately by a higher standard of general education in a body from which it draws annually nearly one hundred recruits.

THE MINUTES OF PROCEEDINGS.

There have been twenty-five Ordinary Meetings, but only fourteen Papers have been read, the discussion upon a single subject having in several instances extended over a greater number of evenings than usual.

The subject of the Paper read at the first meeting of the Session, namely, "Friction-Brake Dynamometers," had not been previously brought forward for consideration by the Institution. It was followed by a descriptive Paper on "The Witham New Outfall Channel and Improvement Works," and by Papers "On the Influence of Chemical Composition on the Strength of Bessemer-Steel Tires," and on "The Friction of Locomotive Slide-Valves." These were all taken before Christmas, and with twelve Other Selected Papers, and Obituary Notices and Abstracts of Papers in Foreign Transactions and Periodicals, form vol. xcv. of the Minutes of Proceedings.

The second Volume of the Session (vol. xcvi., now in the press) covers the period from the 8th of January to the 12th of February inclusive, during which the Papers read and discussed were: "The Compound Principle Applied to Locomotives," which produced a long debate and lengthy correspondence; a group of three Papers on railway steep inclines, namely, "The Trincheras Steep Incline on the Puerto Cabello and Valencia Railway, Venezuela," the "Cost of Working the Hartz Mountain Railway," and "Further Information on the Working of the Fell System of Traction on the Rimutaka Incline, New Zealand;" and lastly, a Paper "On some Canal, River, and other Works in France, Belgium, and Germany," which had come under the notice of the Author in the course of a summer tour. This volume will also contain the reply of Mr. Willans to the correspondence on his Paper on "Non-Condensing Steam-Engine Trials," read in the spring of last year.

Vol. xcvii. will include a record of the Proceedings for the six weeks from the 19th of February to the 2nd of April. The subjects then before the meetings were the very important ones of "Alternate-Current Machinery," "Indian Railways; the Broad and the Narrow-Gauge Systems Contrasted," and "The District Distribution of Steam in the United States." The second of these Papers practically re-opened the controversy, so vigorously carried on sixteen years ago within the walls of the Institution, as to the relative merits and defects of the broad and the narrow gauge for railways, chiefly from the financial side of the question; while the last showed how high-pressure steam had been introduced with advantage to the public for heating, cooking, and power purposes, on tap like gas or water.

The fourth and concluding volume for the session (vol. xcviii.) will embrace the period from the 9th of April to the 28th of May, and will include Papers on "Armour for Ships" and on "The Treatment of Steel by Hydraulic Pressure, and the Plant employed for the Purpose." The Report of the Council will terminate Part I, which will be followed, as usual, by a selection of Articles not read or discussed, Papers by Students, Obituary Notices, and Abstracts from Foreign Transactions.

The Council has made the following awards for Papers read and discussed, further particulars of which will be found in the Appendix to this Report.—A Telford Medal and Telford Premium to Mr. G. Kapp; Watt Medals and Telford Premiums to Mr. W. H. Greenwood and Dr. C. E. Emery; a George Stephenson Medal and a Telford Premium to Mr. E. Worthington; and Telford Premiums to Messrs. J. A. F. Aspinall and J. O. Arnold.

For Papers to be printed in the Proceedings, without being discussed—a Watt Medal and a Telford Premium to Mr. R. Runeberg; and Telford Premiums to Messrs. B. Donkin, Jun., V. A. Dwelshauvers Dery, R. H. Smith, L. F. Vernon-Harcourt, G. Lopes and N. Kennedy.

The Ordinary Meetings.

The average number of persons present at the Tuesday Evening Meetings has been 221, of whom 27·8 per cent. were Members, 30 per cent. Associate Members, 2·6 per cent. Associates, 19 per cent. Students, and 20·6 per cent. Visitors. Reckoned on the number of names on the register on the 2nd of January, somewhat under 2·9 per cent. of the Corporate Members and Associates have been present at the Meetings and 4·4 per cent. of the Students. Compared with former years, this shows a falling-off in the attendances, not only relatively but absolutely.

Students Meetings and Visits to Works.

Twelve Supplemental Meetings for Students were held on Friday evenings from November to April inclusive, generally at intervals of a fortnight. The permission granted by the Council to each Student to introduce a visitor of the age of that class has been taken advantage of to a limited extent. The attendance of Students at these meetings has slightly exceeded 4·8 per cent. of the class;

and there has been an improvement, both in numbers and in the vigour with which the discussions have been carried on.

Of thirteen Papers which were read and discussed it has been determined to print four, containing the results of experiments or of original investigations of interest, namely, "Experiments on Beams," by E. C. de Segundo; "The Cyclical Velocity-Fluctuations of Steam- and other Engines," by H. B. Ransom; "Water Softening and Filtering Apparatus at the Taff Vale Railway Company's Penarth Dock Station, near Cardiff," by W. W. F. Pullen, Wh.Sc.; and "Flexible Wheel-bases of Railway Rolling-Stock," by J. D. Twinberrow.

The Miller Scholarship, 1888–89, has been assigned to the Author of the first-mentioned of these Papers, and Miller Prizes will be given for the remaining Papers. In addition, four others have been considered worthy of recognition, and the Council has accordingly granted Miller Prizes for the following communications:—"Electrical Measuring Instruments," by S. Joyce; "Moulding and Casting Cylinders for Marine Engines," by R. J. Durley, B.Sc.; "The 26-knot Spanish Torpedo-Boat, 'Ariéte,'" by J. King-Salter; and "Photography for Engineers," by C. H. Gale and V. W. Delves-Broughton.

The visits by the Students during the past Session included the establishment of Mr. P. Brotherhood, Lambeth; the New Reservoir of the Grand Junction Waterworks Co. at Hanger Hill, Ealing; the steamship "Orizaba," belonging to the Orient Steam Navigation Co., at Tilbury Docks; the Locomotive, Carriage, and Wagon Works of the North London Railway, Bow Road; the works of the Series Electrical Traction Syndicate at Northfleet; the railway-signal works of Messrs. Saxby and Farmer at Kilburn; the works of Messrs. Siemens, Charlton; the Woolwich ferry; the marine-engine works of Messrs. Humphrys, Tennant & Co., Deptford; the works of Messrs. Bryan Donkin & Co., Bermondsey; and the Royal Mint.

CRAMPTON PRIZE.

Intimation was received from the executors of the late Mr. Thomas Russell Crampton of a bequest of £500 in trust, in terms of the following extract from the will of the deceased:—

"I bequeath the sum of Five Hundred Pounds to the Institute of Civil Engineers upon Trust that the Council of the Institute shall found a prize to be called the 'Crampton Prize' so that the Interest of the said Legacy shall be annually expended on a medal or books, or otherwise as the Institute shall think fit for presentation to the Author of the best paper on 'The Construction Ventilation and Working of Tunnels of Considerable Length' and in case in any year no Paper received by the Institute shall be deemed worthy to be adjudicated the annual prize then the Institute shall for that year allot the prize by way of reward for a paper on any other subject that they may select."

The Council has, on behalf of the Institution, accepted this trust, which is welcome, as tending to perpetuate the memory of a member whose ingenuity gained him great eminence as an engineer, and whose kindness of heart endeared him to a large circle of friends.

FINANCE.

The Abstracts of Receipts and Expenditure, signed by the Auditors and appended to this Report, calls for very little comment. The gross receipts for the year amounted to £21,763 18*s.* 4*d.* as against £20,753 18*s.* 5*d.* for the previous twelve months. Under the three main heads on this side of the account, the amounts received during the year ending the 31st of March, 1889, were as follow:—Income, £17,400 13*s.* 3*d.* of which £14,575 12*s.* 6*d.* represented subscriptions, £1,723 14*s.* dividends, and £703 15*s.* rents from No. 26, Great George Street; Capital, £3,840 18*s.*; and Trust Funds, £522 7*s.* 1*d.* It may be mentioned that the legacy bequeathed by the late Sir Joseph Whitworth, viz., eighty shares of £25 each in the firm of Sir Joseph Whitworth & Co., or nominally £2,000, was, on the constitution of that firm as a limited liability company last year, converted into four hundred £10 shares and £1,400 5 per cent. Debenture Stock, or nominally £5,400. It will be noticed also in connection with the investments, both on Institution and Trust Funds accounts, that the amounts formerly standing in New Threes, Consols, and Reduced Threes, are now—in accordance with the conversion scheme of the Chancellor of the Exchequer—represented by equivalent sums in 2¾ per cent. Stock.

The total expenditure for the year amounted to £18,226 6*s.* 4*d.* as against £20,909 16*s.* 6*d.* for the previous twelve months. In explanation of this apparent decrease, it should be stated that while in the previous year stock was purchased on capital account to the nominal value of £5,000, in the year 1888–89 the capital investment was nominally only £3,000, a like sum being placed on deposit, as will be seen on reference to the balance shown on the 31st of March last. Under the three main heads of General Expenditure, or Income, Capital, and Trust Funds, the payments for the year were respectively £13,972 8*s.* 9*d.*, £3,901 9*s.* 3*d.* (invested in Great Eastern Railway 4 per cent. debenture stock), and £352 8*s.* 4*d.* Some small receipts and payments will be noticed under the head of Capital Extraordinary, an explanation of which account was given in the Report of last year.

Turning to the Summary of Investments, the accuracy of which is duly vouched for by the Auditors, it is satisfactory to find that the total is now £98,042 13*s.* 10*d.*, or £6,400 more than at the same date last year. Of this, £3,400 is the nominal gain on the conversion of the Whitworth Legacy, while the remaining £3,000 represents the investment on capital account made during the year, both of which transactions have already been referred to.

Assessment of Local Rates.

The assessment of the property of the Institution, Nos. 24, 25, and 26, Great George Street, being in the opinion of the Council too high (especially in respect of the first-named house, rated at £834 per annum), the Solicitor was instructed to ascertain if there were reasonable grounds for believing that a reduction could be procured. It having been advised, however, that the best course would be to wait for the next quinquennial valuation, when the Institution would have good ground for seeking to get the assessment reduced, the Council decided to go no further with the matter at present.

Westminster (Parliament Street, &c.) Improvement Act.

An application was received from the promoters, asking that the time for the payment of the £10,000 deposit under Clause 26 of the above Act, should be extended for six months from the 23rd of September 1888. The opinion of the legal advisers, acting in your behalf, being that the Institution could waive their strict rights in the particular suggested, without prejudicing their position under the Act in other respects, the application was complied with. A subsequent application from the same parties for a further extension of three months was also granted on similar conditions.

Menai Suspension Bridge.

It recently came to the knowledge of the Council that the structure of the Menai Suspension Bridge did not record the name of the Engineer, Thomas Telford, first President of the Institution. Thereupon a representation was made to Her Majesty's Office of Works, suggesting the desirability of this information being suitably inscribed on one of the piers of the bridge. The Council has much gratification in announcing that an official communication has been received from the Office of Works, thanking the Institution for the suggestion, and undertaking to carry it out.

PICTURES.

In connection with the Retrospective Exhibition of means of Transport, forming part of the Paris Exhibition, the Council was requested to lend some of the historical paintings from the collection of the Institution. A selection of portraits of some of the most eminent Past Presidents, and others connected with the railway-system, having been approved, arrangements were made for its transmission to Paris. At the last moment, however, intimation was received that the wall-space at the disposal of the British Committee was insufficient, and that the proposed exhibit could not be made. As the negotiations resulted in the acquirement of some particulars in connection with these works of art, which have never yet been printed in a collected form, it has been thought advisable to give, in the Appendix to this Report, a complete list of the oil-paintings in the possession of the Institution with the names of the artists.

The Council anticipates an unusually interesting year for its successors, not only on account of the progress being made with public works in the British Empire, but from the remarkable character of the Exhibition which has been opened under the auspices of the French Government. The important mechanical contents and the imposing structures of this monumental under taking cannot fail to attract all who are interested in engineering progress; while the visit to France of many American Engineers (who have promised to accept on their way the hospitality of their professional brethren here) will add to the general interest of the season. The establishment, in connection with the Exhibition, of a series of congresses on scientific subjects is a happy feature, likely to be productive of much good by bringing together the greatest intellects of different nations, and by developing new and valuable views on the subjects treated of. The Council is pleased to learn that many of the leading English members of the engineering profession have been invited to take special part in these meetings, and is sure that The Institution of Civil Engineers will meet there with due recognition.

[ABSTRACT OF RECEIPTS AND EXPENDITURE.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS

	Dr.		£ s. d.	£ s. d.
	To Balance, March 31st, 1888, viz. —			
	Cash in the hands of Treasurer		1,924 15 1	
	" " Secretary		25 15 5	1,950 10 6
		INCOME. £ s. d.		
	— Subscriptions —			
	Arrears	474 12 0		
	Current	13,915 15 6		
	Advance	185 5 0	14,575 12 6	
	— Library Fund		131 7 0	
	— Minutes of Proceedings.—Repayment for Binding, &c.		256 12 1	
	— Publication Fund		1 1 0	
	— Dividends, 15 months on			
£	*Institution Investments.*			
6,000	2¾ per cent. Stock	215 0 0		
	1 year on			
4,000	Metropolitan Board of Works 3½ Stock	201 10 8		
3,000	Great Northern Railway 4% Debenture Stock	116 17 6		
3,000	Great Western Ditto	116 17 6		
3,000	Lanc. and Yorks. Ditto	116 17 6		
8,000	London & N. W. Ditto	311 13 4		
3,000	Midland Ditto	116 17 6		
3,000	North Eastern Ditto	116 17 6	1,313 11 6	
£33,000	Total nominal or par value			
	— Ditto, 6 months on			
	Whitworth Legacy.			
£2,000	Eighty £25 Shares in Sir J. Whitworth & Co., Ltd.	250 0 0		
	Converted into—			
1,400	5% Debenture Stock, Do.	34 2 6		
	Interim on			
4,000	Four hundred £10 shares Ditto	120 0 0	404 2 6	
£5,400				
	— Rents, No. 26 Great George Street		703 15 0	
	— Interest on Deposit		8 11 8	17,400 13 3
		CAPITAL.		
	— Admission Fees		3,085 19 0	
	— Life-Compositions		754 19 0	3,840 18 0
	Carried forward			£23,192 1 9

from the 1ST APRIL, 1888, *to the* 31ST MARCH, 1889.

EXPENDITURE.

GENERAL EXPENDITURE

	£	s.	d.	£	s.	d.	£	s.	d.
By House and Establishment Charges:—									
Repairs:— No. 25 Gt George St.	112	12	8						
No. 26 Gt. George St.	54	7	1						
				166	19	9			
Rates and Taxes:—									
No. 24 Gt. George St.	273	8	9						
No. 25 Gt. George St.	408	5	5						
No. 26 Gt. George St.	173	0	5						
				854	14	7			
Insurance:—No. 24 Gt. George St.	13	14	6						
No. 25 Gt. George St.	38	17	6						
No. 26 Gt. George St	4	10	0						
				57	2	0			
Rent of Telephone				23	13	0			
Fixtures and Furniture				196	8	8			
Lighting and Warming:—									
No. 24 Gt. George St	12	5	4						
No. 25 Gt. George St	157	4	5						
No. 26 Gt. George St	13	14	1						
				183	3	10			
Refreshments at Meetings				58	19	5			
Assistance at Meetings				33	14	0			
Students Meetings				23	16	8			
Household Expenses				184	7	8			
							1,782	19	7
— Postages, Telegrams, and Parcels				260	6	9			
— Stationery and Printing				527	14	6			
— Watt Medals				7	2	6			
— George Stephenson Medal				2	7	6			
— Diplomas				47	11	6			
— Annual Dinner (balance 1888)				77	13	6			
							922	16	3
— Salaries				2,100	0	0			
— Clerks, Messengers, and Housekeeper				790	0	0			
— Donation to late Housekeeper				30	0	0			
— Donation to late Messenger				52	0	0			
							2,972	0	0
— Library:—Books				302	12	3			
Periodicals				46	1	11			
Binding				204	5	10			
							553	0	0
— Publications:—									
"Minutes of Proceedings," Vols. xcii., xciii., xciv. and xcv.				7,238	1	8			
Charter, By-Laws, and Lists of Members				85	9	9			
							7,323	11	5
— Architects Registration Bill							82	9	6
— Legal Expenses:—									
General				35	12	0			
Corporation Duty				300	0	0			
							335	12	0
							£13,972	8	
CAPITAL.									
— Purchase of £3,000 G. E. Ry. 4 % Debenture Stock							3,901	9	
Carried forward							£17,873	18	0

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*continued.*

Dr.

£. s. d.		£. s. d.	£. s. d.	£. s. d.
	Brought forward			23,192 1 9
	TRUST-FUNDS.			
	Telford Fund.			
	To Dividends:—1 year on			
5,425 11 9	2¾% Stock (paid as 3%)	158 10 8		
	Bonus on Conversion.	13 11 3		
	: 15 months on			
3,290 13 0	Ditto (Unexpended Dividends).	120 2 6		
	Bonus on Conversion.	8 4 6	300 8 11	
8,716 4 9				
	Manby Donation.			
	: 1 year on			
250 0 0	Great Eastern Ry. 4% Debenture Stock		9 14 9	
	Miller Fund.			
	: 15 months on			
3,125 0 0	2¾% Stock (paid as 3%)	114 1 5		
1,999 14 7	Ditto (Unexpended Dividends)	72 19 4		
	Bonus on Conversion.	5 0 0	192 0 9	
5,124 14 7				
	Howard Bequest			
551 14 6	2¾% Stock (paid as 3%)		20 2 8	
				522 7 1
				£23,714 8 10

CAPITAL RECEIPTS—EXTRAORDINARY.

	£. s. d.
To Balance from Yearly Receipts, viz.:—	177 14 0
— Rent of Stables in Tufton Street (one quarter)	16 15 0
	£194 9 0

SUMMARY OF INVESTMENTS.

	£. s. d.	£. s. d.
INSTITUTION INVESTMENTS		38,000 0 0
FREEHOLDS OF NOS. 24, 25 & 26 GREAT GEORGE STREET		40,000 0 0
WHITWORTH LEGACY:—400 SHARES OF £10, AND £1,400 5% DEBENTURE STOCK IN THE FIRM OF SIR JOSEPH WHITWORTH AND CO., Lt.		5,400 0 0
TRUST-FUNDS INVESTMENTS:—		
Telford Fund	8,716 4 9	
Manby Donation	250 0 0	
Miller Fund	5,124 14 7	
Howard Bequest	551 14 6	
		14,642 13 10
		£98,042 13 10

from the 1st APRIL, 1888, *to the* 31st MARCH, 1889.

EXPENDITURE—*continued.*

Cr.

			£. s. d.
Brought forward			17,873 18 0
TRUST FUNDS.			
By Telford Premiums	185 13 8		
— Telford Medals	9 0 0		
		194 13 8	
— Manby Premium		20 0 0	
— Miller Scholarship	40 0 0		
— Miller Prizes	97 14 8		
		137 14 8	
			352 8 4
			18,226 6 4
— Balance, March 31st, 1889.—			
On deposit		3,000 0 0	
Cash in the hands of the Treasurer		2,265 13 10	
" " Secretary		44 14 8	
			5,310 8 6
			23,536 14 10
— Transferred to Credit of Capital Receipts—Extraordinary			177 14 0
			£23,714 8 10

CAPITAL EXPENDITURE—EXTRAORDINARY.

— Surveyor's Charges.—		
re No 26 Great George Street		31 10 0
— Stables in Tufton Street:—		
Rent	120 0 0	
Water Rate	2 1 8	
Repairs	33 10 4	
Commission on Letting, &c.	7 7 0	
		162 19 0
		£194 9 0

Examined with the Books and found correct.

(Signed) ROB. W. GRAHAM, } *Auditors*
A. McKERROW, }

JAMES FORREST, *Secretary.*
13 *April*, 1889.

PREMIUMS AWARDED.

SESSION 1888–89.

THE COUNCIL of The Institution of Civil Engineers has awarded the following Premiums:—

FOR PAPERS READ AND DISCUSSED AT THE ORDINARY MEETINGS.

1. A Telford Medal and a Telford Premium to Gisbert Kapp,[1] Assoc. M. Inst. C.E., for his Paper on "Alternate-Current Machinery."
2. A Watt Medal and a Telford Premium to William Henry Greenwood, M. Inst. C.E., for his Paper on "The Treatment of Steel by Hydraulic Pressure, and the Plant employed for the purpose."
3. A George Stephenson Medal and a Telford Premium to Edgar Worthington, B.Sc., Assoc. M. Inst. C.E., for his Paper on "The Compound Principle applied to Locomotives."
4. A Watt Medal and a Telford Premium to Charles Edward Emery, Ph.D., M. Inst. C.E., for his Paper on "The District Distribution of Steam in the United States."
5. A Telford Premium to John Audley Frederick Aspinall, M. Inst. C.E., for his Paper on "The Friction of Locomotive Slide-Valves."
6. A Telford Premium to John Oliver Arnold, F.C.S., for his Paper on "The Influence of Chemical Composition on the Strength of Bessemer-Steel Tires."

FOR PAPERS PRINTED IN THE PROCEEDINGS WITHOUT BEING DISCUSSED.

1. A Watt Medal and a Telford Premium to Robert Runeberg, Assoc. M. Inst. C.E., for his description of "Steamers for Winter Navigation and Ice-breaking."
2. A Telford Premium to Bryan Donkin, jun., M. Inst. C.E., for his account of "Experiments with Gas-flame Jackets."
3. A Telford Premium to Professor Victor Auguste Ernest Dwelshauvers Dery,[2] for his "Reduction of Experiments on the Effect of Super-heating, Steam-jacketing, and Gas-flame Jackets on Cylinder Condensation."

---

[1] Has previously received a Telford Medal and a Telford Premium.

[2] Has previously received a Watt Medal and a Telford Premium.

4. A Telford Premium to Robert Henry Smith, Assoc. M. Inst. C.E., for his Paper on "Stress Diagrams of Solid Structures."
5. A Telford Premium to Leveson Francis Vernon-Harcourt,[1] M.A., M. Inst. C.E., for his Paper on "Alpine Engineering."
6. A Telford Premium to George Lopes, B.A., Assoc. M. Inst. C.E., for his Account of "The Reparation of Betchworth Tunnel, Dorking, on the London, Brighton and South Coast Railway."
7. A Telford Premium to Neil Kennedy, M. Inst. C.E., for his Paper on "The Tacheometer and its Uses."

FOR PAPERS READ AT THE SUPPLEMENTAL MEETINGS OF STUDENTS.

1. The Miller Scholarship to Edward Carstensen de Segundo,[2] Stud. Inst. C.E., for his account of "Experiments on the Strain in the Outer Layers of Cast-Iron and Steel Beams."
2. A Miller Prize to Henry Byrom Ransom, Stud. Inst. C.E., for his Paper on "The Cyclical Velocity-Variations of Steam- and other Engines."
3. A Miller Prize to William Wade Fitzherbert Pullen, Wh.Sc., Stud. Inst. C.E., for his account of "Water-Softening and Filtering Apparatus, for Locomotive Purposes, at the Penarth Dock Station near Cardiff, of the Taff Vale Railway Company."
4. A Miller Prize to James Denis Twinberrow, Stud. Inst. C.E., for his Paper on "Flexible Wheel-bases of Railway Rolling-Stock."
5. A Miller Prize to Samuel Joyce, Jun., Stud. Inst. C.E., for his Paper on "Electrical-Measuring Instruments; their Properties and Calibration."
6. A Miller Prize to Richard John Durley, B.Sc., Stud. Inst. C.E., for his Paper on "Moulding and Casting Cylinders for Marine Engines."
7. A Miller Prize to Julian James King-Salter, Stud. Inst. C.E., for his description of "The 26-knot Spanish Torpedo-Boat 'Ariéte.'"
8. Miller Prizes to Charles Henry Gale, Stud. Inst. C.E., and Vernon Warburton Delves-Broughton, Stud. Inst. C.E., for their joint Paper on "Photography for Engineers."

⁂ It has been determined to print the first four Students' Papers, either in whole or in part, in the Minutes of Proceedings.

---

[1] Has previously received a Telford Medal and Telford and Manby Premiums.

[2] Has previously received a Miller Prize.

SUBJECTS FOR PAPERS.

SESSION 1889–90.

THE COUNCIL of The Institution of Civil Engineers invites Original Communications on the Subjects included in the following List, as well as on any other questions of professional interest. This list is to be taken merely as suggestive, and not in any sense as exhaustive. For approved Papers the Council has the power to award Premiums, arising out of Special Funds bequeathed for the purpose, the particulars of which are as under:—

1. The TELFORD FUND, left "in trust, the Interest to be expended in Annual Premiums, under the direction of the Council." This bequest (with accumulations of dividends) produces £260 annually.

2. The MANBY DONATION, of the value of about £10 a year, given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings."

3. The MILLER FUND, bequeathed by the testator "for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" This Fund (with accumulations of dividends) realises £150 per annum. Out of this Fund the Council has established a Scholarship,—called "The Miller Scholarship of The Institution of Civil Engineers,"—and is prepared to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years.

4. The HOWARD BEQUEST, directed by the testator to be applied "for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the Uses or Properties of Iron or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution." The annual income amounts to nearly £16. It has been arranged to award this prize every five years, commencing from 1877. The next award will therefore be made in 1892.

The Council will not make any award unless a communication of adequate merit is received, but will give more than one Premium if there are several deserving memoirs on the same subject. In the adjudication of the Premiums no distinction will be made between essays received from members of the Institution or strangers, whether Natives or Foreigners, except in the cases of the Miller and the Howard bequests, which are limited by the donors.

LIST.

1. The Utilization of Unused Sources of Power in Nature—such as the Tides, the Radiant Heat of the Sun, &c.
2. Standard Specifications for the Materials used in the Construction of Engineering Works.
3. The influence of Sea-Water upon Portland-Cement Mortar and Concrete.
4. On Foundations of great depth, illustrated by examples.
5. Recent Improvements in Tunnelling and deep Shaft-sinking.
6. The Construction, Ventilation, and Working, of Railway Tunnels of great length.
7. Description of any new or peculiar type of Mountain Railway for very steep gradients.
8. Recent Improvements in Cable and Electrical Tramways.
9. The Value, with respect to the safety and durability of Metallic Bridges, of (*a*) increase in the weight of the structure, by the choice of other than the lightest design; (*b*) increase in the dead load, by the adoption of a heavy description of flooring, with or without the addition of concrete or ballast.
10. The Causes of the Formation of Bars under water and the means for removing them.
11. Recent examples of Hydraulic-Lift Graving-Docks.
12. The Laying-out and Equipment of River-Ports such as Frankfort-on-Main, with reference to improved methods of transshipping merchandise.
13. Forms and Construction of Masonry Dams for Reservoirs.
14. The Cleaning and Deepening of Drainage- and Irrigation-Canals by mechanical means.
15. On Water Meters and the Sale of Water by Measure.
16. Descriptions of Mining-Machinery of improved design.
17. Gold-quartz Reduction and Amalgamation—description of the various machines, and of their method of working.
18. The Value of Laboratory Tests as compared with subsequent practical results.

19. The Working-Strength of Iron and Steel as affected by (*a*) the amplitude; (*b*) the frequency; and (*c*) the time-rate of the stress-variations.
20. The effect upon Basic Steel of (*a*) Chromium; (*b*) Aluminium; and (*c*) Tungsten.
21. The Properties of Bronzes and other Alloys.
22. The Corrosion of Metal Structures, and the best means of preserving them.
23. The Effect of Wind upon Structures, as influenced by (*a*) their superficial area; (*b*) the form or position of the exposed surfaces; (*c*) the shelter of adjacent bodies; and (*d*) the dynamic action of sudden gusts.
24 The Construction of the Working-Parts of Steam-Engines, in relation to the high pressures and temperatures now becoming general.
25. Results of the extended use of Steam at High Pressures at Sea.
26. The various systems of Forced Draught in Boilers, with the economical results obtained.
27. The most recent types of (*a*) Mail-Steamers; (*b*) Cargo-Steamers; and (*c*) War-Ships.
28. The Distribution of Armour and of Armament in Battle Ships.
29. The Application of Steel Castings and of Steel Forgings to Ordnance Construction.
30. On modern experience in Screw Propulsion, comprising the comparative efficiency of propellers of large diameter, and of smaller ones deeply immersed, and of the influence of form.
31. On the Highest Speeds attained and attainable on Railways, having reference to gradients, curves, and the locomotives employed.
32. Mechanical Traction on Common Roads.
33. The Petroleum-Engine and its Applications.
34. The Distribution of Power by Compressed Air or by Vacuum, and the Construction of Machines to be worked by Compressed Air or by Vacuum.
35. Hydraulic Pumps for Working at High Pressures.
36. The means of governing and economizing high-pressure fluid in Hydraulic Cranes, Engines, etc.
37. The Design, Construction, and Capacity of Fans, with experimental results.
38. The Construction and Working of Windmills suitable for raising Water for the supply of Villages and isolated houses.
39. The best Combined System of Warming, Ventilating, and Lighting large buildings.

40. The Utilization of Natural Oils for the Manufacture of Illuminating Gas.
41. The Plant used in the execution of large Engineering Structures.
42. Tools used in the building of Iron and Steel Ships, and in the Construction of Boilers.
43. Liquid Fuel Motors.
44. Electric Meters for recording the Consumption of Electrical Energy.
45. The Construction and Maintenance of Secondary Batteries.
46. The application of Electricity to the Working of Cranes, Pumps, Tools, etc.
47. The application of Electricity to Smelting and Metallurgical Operations.
48. The application of Electricity to the Purification of Water and of Sewage.
49. The Purification of Copper, and the Reduction of Copper Ores by Electrolytic processes.
50. Contributions to the Bibliography of special branches of Engineering.

Instructions for Preparing Communications.

In writing these Essays the use of the first person should be avoided. They should be legibly transcribed on foolscap paper, on one side only, leaving a margin on the left side, in order that the sheets may be bound. Every Paper must be prefaced by an Abstract of its contents not exceeding 1,500 words in length.

Illustrations, when necessary, should be drawn on tracing-paper, to as small a scale as is consistent with distinctness, but in no case should any Figure exceed 6½ inches in height. When an illustrated communication is accepted for reading, a series of Diagrams will be required sufficiently large and boldly coloured to be clearly visible at a distance of 60 feet. These diagrams will be returned.

Papers which have been read at the Meetings of other Societies, or have been published, cannot be read at a Meeting of the Institution, nor be admitted in competition for the Premiums.

The Communications must be forwarded to the Secretary of the Institution, from whom any further information may be obtained.

There is no specified date for the delivery of MSS., as when a Paper is not in time for one session it is dealt with in the succeeding one.

WILLIAM POLE, *Honorary Secretary.*
JAMES FORREST, *Secretary.*

THE INSTITUTION OF CIVIL ENGINEERS,
25, *Great George Street, Westminster, S.W.*
September, 1889.

EXCERPT BY-LAWS, SECTION XV., CLAUSE 3.

"Every Paper, Map, Plan, Drawing, or Model, presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper. But should the Council refuse or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. Except as hereintofore provided, no person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

NOTICE.

It has frequently occurred that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors have advanced somewhat doubtful theories, or have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat, that the Institution as a body must not be considered responsible for the facts and opinions advanced in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the inquiry; but that such notice, or award, must not be regarded as an expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

ORIGINAL COMMUNICATIONS.

RECEIVED BETWEEN APRIL 1, 1888, AND MARCH 31, 1889.

AUTHORS.

Alley, S. No. 2,394.—Tests of a Westinghouse Engine. (Vol. xcvi., p. 295.)

Barnaby, Sir N. No. 2,399. Armour for Ships. With 6 Tracings. (*Ante*, p. 1.)

Barron, J. No. 2,393.—Some Recently-constructed Piers and Harbours on the North and West Coasts of Scotland. With 5 Drawings.

Barry, P. No. 2,384.—On the Deep-water Quays Constructed in the Port at Cork. With 3 Drawings.

Baterden, J. R. No. 2,335.—Concrete Graving Dock at Blyth. With a Sheet of Tracings.

Bruce, A. F. No. 2,342.—Water-Supply of some Italian Towns. With a Tracing.

Carey, A. E. No. 2,385.—The Inspection of Portland Cement for Public Works. With 6 Appendixes and 2 Figs.

Carruthers, J. No. 2,375.—The Trincheras Steep Incline on the Puerto Cabello and Valencia Railway, Venezuela. (Vol. xcvi., p. 120.)

Chatham, W. No. 2,374.—The Improvement of the River Avon below Bristol. With 3 Tracings. (*Post*, p. 280.)

Crawfurd, J. B. No. 2,349.—Note on the Sinkage of Embankments on Soft Alluvial Ground. With 1 Drawing.

Crimp, W. S. No. 2,395.—Experiments on the Movements of Sewer-Air at Wimbledon, 1888. (Vol. xcvii., p. 383.)

Cruttwell, G. E. W. No. 2,401.—The New Bridge of the London, Chatham and Dover Railway over the Thames at Blackfriars. With 9 Sheets of Illustrations.

Donkin, B., junior. No. 2,403.—Experiments on a Steam-Engine, the Cylinder of which was heated externally by Gas-flames. (*Post*, p. 250.)

Duckham, F. E. No. 2,365.—Underpinning Great Yarmouth Town Hall. With a Tracing.

AUTHORS.

Dwelshauvers Dery, Professor V. A. E. No. 2,403*a*.—Investigation of the Heat-Expenditure in Steam-Engines, especially with reference to Methods of Diminishing Cylinder-Condensation. With a Table and 2 Tracings. (*Post*, p. 254.)

Fletcher, J. W. No. 2,346.—On Balancing or Overcoming the Effects of Foreign Currents on Telegraph-Circuits. With a Specimen, 2 Sheets of Tables, 1 Tracing and 22 Maps. (Vol. xciv., p. 259.)

Fowler, A. F. No. 2,387.—Naburn New Lock.

Gardiner, J. No. 2,356.—A New Method of Determining Latitude for Geodetic Purposes, &c.

Gloyne, R. M. No. 2,360.—Multipliers and Curves for Ascertaining the Discharge, &c., at Various Depths in the Same Sewer. (Vol. xcvi., p. 268.)

Greenwood, W. H. No. 2,402.—The Treatment of Steel by Hydraulic Pressure, and the Plant Employed for the Purpose. With an Abstract and 18 Illustrations. (*Ante*, p. 83.)

Hart, C. F. No. 2,397.—Somerset Coal Canal.

Hart, J. W. No. 2,386.—Shanghai Waterworks. With 6 Drawings and 5 Photographs, also an Album of Views.

Haswell, C. H. No. 2,382.—Design of a Double Arch for Floors and Roofs of Subways. With a Tracing.

Hett, C. L. No. 2,352.—Experiments on Steam-jet Exhaustion. With 2 Tracings.

Hunter, G. M. No. 2,333.—The Manufacture of Oil-Gas on the Pintsch System, and its Application to the Lighting of Railway-Carriages. With Appendix and 3 Tracings. (Vol. xcv., p. 218.)

Jones, M. V. No. 2,347.—An Improved, Safe and Economic Management of the Marine Engine.

————. No. 2,362.—On the Explosion and Spontaneous Combustion of Coal in Ships, its Prevention, &c.

————. No. 2,370.—Sub-aqueous Blasting. With 2 Tracings.

Kapp, G. No. 2,392.—Alternate-Current Machinery. With 2 Sheets of Illustrations. (Vol. xcvii., p. 1.)

Ker, T. No. 2,381.—Concrete Quarters for Native Clerks, Guards, and Menial Staff on Indian Railways. With 4 Tracings.

Kirkaldy, J. No. 2,343.—Distilling Plant for the Production of Fresh Drinking-water, designed for the Italian Government for use at Massowah. With 4 Sheets of Illustrations.

AUTHORS.

Leslie, J. No. 2,388.—Observations on the Amount of Loss of Rain-water by Evaporation, Vegetation, &c.

Litster, D. M. No. 2,351. Foundations of the Daly College, Indore. With 3 Tracings and 2 Photographs. (Vol. xcvii., p. 352.)

Lobnitz, F. No. 2,378. The Removal of Rock under Water without Explosives. With Photographs and 2 Sheets of Drawings. (Vol. xcvii., p. 369.)

Lopes, G. No. 2,338.—The Reparation of Betchworth Tunnel, Dorking, on the London, Brighton and South Coast Railway. With 6 Tracings. (Vol. xcv., p. 291.)

Lucas, J. No. 2,389.—The Chalk Water System, Chiltern Range Section. With 3 Maps.

Macalister, D. No. 2,341. The River Clyde. With 5 Tracings and 2 Photographs. (Vol. xcv., p. 279.)

Mackintosh, P. A. No. 2,350.—The Bodmin and Wadebridge Railway. With 7 Tracings.

Maxwell, J. P. No. 2,357.—Further Information on the Working of the Fell System of Traction on the Rimutaka Incline, New Zealand. With 3 Tracings. (Vol. xcvi., p. 137.)

Morrison, G. J. No. 2,376.—On the Breach in the Embankment of the Yellow River. With 2 Tracings and Map.

Mountain, A. C. No. 2,334.—Paved Carriage-ways in Sydney, New South Wales. With Map, Tracing, 4 Appendixes, and samples of Australian timber. (Vol. xciii., p. 364.)

Olive, W. T. No. 2,344.—Alterations at Westhead's Weir on the Medlock, Manchester. With 4 Sheets of Illustrations.

————. No. 2,391.—The Manchester Corporation Tramways. With 6 Figs., 2 Tracings, and a Map.

Otgawa, M. No. 2,355.—Remarks on River Crossing and Bridge-Piers.

Park, J. C. No. 2,383.—Balanced Slide-Valves. With 11 Tracings. (*Post*, p. 369.)

Parkinson, R. M. No. 2,340.—The Design of Railway-Stations and Yards. With an Abstract, Table, and 5 Tracings.

Quick, G. No. 2,390.—Perforated Cake-Powder for Ordnance. With Table of Results of Experiments and 4 Sheets of Tracings. (Vol. xcvii., p. 342.)

Renwick, C. No. 2,369.—Triple Propeller Propulsion of Ironclads.

Roehricht, R. H. O. No. 2,368.—The Duplication of the Railway Line between Brisbane and Ipswich, Queensland. With 7 sheets of Illustrations.

AUTHORS.

Runeberg, R. No. 2,371.—On Steamers for Winter Navigation and Ice-breaking. With 8 Sheets of Drawings and 2 Photographs. (Vol. xcvii., p. 277.)

Sandberg, C. P. No. 2,366.—On the Use of Heavier Rails for Safety and Economy in Railway Traffic. (Vol. xcv., p. 354.)

Sawyer, E. E. No. 2,372.—West of India Portuguese Railway and Harbour Works. With 13 Drawings. (Vol. xcvii., p. 302.)

Shellshear, W. No. 2,367.—Renewing the Timber Platforms of Penrith Bridge over the Nepean River, New South Wales. With a Tracing.

Smith, J. W. No. 2,336.—Hurst's Triangular Prismatic Formula for Earthwork compared with the Prismoidal Formula. With 11 Figs. (Vol. xcv., p. 229.)

Thomson, J. P. No. 2,353.—The Blackall Artesian Well, Queensland.

Unwin, Prof. W. C. No. 2,345.—The Transmission of Power to great distances by Compressed Air. With 3 Figs. (Vol. xciii., p. 421.)

Vernon-Harcourt, L. F. No. 2,339.—Alpine Engineering. With an Appendix, and 3 Sheets of Tracings. (Vol. xcv., p. 237.)

———————, ———. No. 2,363.—Some Canal, River, and other Works in France, Belgium, and Germany. With 1 Plate. (Vol. xcvi., p. 182.)

Vickery, S. K. No. 2,348.—The Practice of Surveying in the Australasian Colonies. With an Abstract, 2 Sketches and Tables. (Vol. xcv., p. 211.)

Walton, F. T. G. No. 2,398.—Construction of the Dufferin Bridge over the Ganges at Benares. With 7 Tracings.

Wearing, W. No. 2,400.—Description of the Failures and Restoration of the Embankment of the Grizedale Reservoir. With a Tracing.

Webster, J. J. No. 2,396.—Foot-bridge over the River Ouse at Bedford. With 2 Drawings and a Photograph.

Wilson, R. No. 2,379.—Cost of Working the Hartz Mountain Railway. (Vol. xcvi., p. 131.)

Worthington, E. No. 2,364.—The Compound Principle applied to Locomotives. With 8 Sheets of Illustrations. [(Vol. xcvi., p. 2.)

LIST OF DONORS TO THE LIBRARY.

FROM APRIL 1, 1888, TO MARCH 31, 1889.

A.

Abt, R.
Académie de Lausanne.
Académie Royale de Belgique.
Adams & Co.
Adamson, D.
Adelaide University.
Admiralty.
Aëronautical Society of Great Britain.
Agent-General for New South Wales.
Åkerman, Prof. R.
American Academy of Arts and Sciences.
American Association for the Advancement of Science.
"American Engineer."
American Institute of Electrical Engineers.
American Institute of Mining Engineers.
American Railway Master Mechanics' Association.
American Society of Civil Engineers.
American Society of Mechanical Engineers.
Anderson, G. G.
Andrews, G. R.
Andrews, Col. J.
Andrews, T., F.R.SS. L. & E.
"Annalen für Gewerbe und Bauwesen."
"Annales des Mines."
"Annales des Ponts et Chaussées."
"Annales des Travaux Publics."
"Annales Industrielles."
Aramburu, F.
"Architects' Register, The."
Architectural Association.
Architekten- und Ingenieur-Verein, Hannover.
Arkansas Society of Engineers, Architects, and Surveyors.
Art Union of London.
Ashburner, C. A.
Asiatic Society of Bengal.
Askenasy, A.
Asociacion de Ingenieros Industriales.
Association Alsacienne des Propriétaires d'Appareils à Vapeur.
Association Amicale des Anciens Élèves de l'École Centrale des Arts et Manufactures.
Association des Ingénieurs sortis de l'École de Gand.
Association des Ingénieurs sortis de l'École de Liége.
Association of Chambers of Commerce of the United Kingdom.
Association of Engineering Societies, U.S.A.
Association of Municipal and Sanitary Engineers and Surveyors.

Association pour prévenir les Accidents de Fabrique.
Astronomer Royal.
"Athenæum, The."
Attwood, G.
Aveling and Porter.

B.

Babbage, Maj.-Gen. H. P.
Baldaque, A. A.
Balfour, D.
Banister, F. D.
Barclay, A.
Barcroft, H.
Barr, A.
Barry, J. W.
Bateman, Parsons and Bateman.
Bauerman, H.
Baxter, W. H.
Bazalgette, Sir J. W., C.B.
Bazin, H.
Beaumont, W. W.
Beck and Company, Limited.
Belelubsky, Prof. N.
Benét, Brig.-Gen. S. V., U.S. Army.
Bennett, A. R.
Bennett, J. & Co.
Bey, V.
Bimetallic League, Manchester.
Binnie, A. R.
Bird, F. & Co.
Birkenhead Free Public Library.
Birmingham Architectural Association.
Blackett, J.
Blaine, R. G.
Blanford, H. F., F.R.S.
Blum, A. S.
Board of Trade.
Bombay Branch of the Royal Asiatic Society.
Bombay Port Trust.
"Bombay Quarterly Civil List, The."
Bonnin, R.
Botting, F.
Bouscaren, G.
Bowes-Scott and Read.
Bradford Technical College.
Bramwell, Sir F. J., Bart., D.C.L., F.R.S.
Brereton, R. P.
Bretland, J. C.
Bright, Lady.
Bristol Wagon Works Company, Limited.
British Iron Trade Association.
Broad & Co.
Brown, A.
Brown and Sharpe Manufacturing Company.
Browning, A. G.
"Bulletin du Canal de Suez."
"Bulletin du Canal Interocéanique."
Bund, J. J. W.
Burstal, E. K.

C.

Cairncross, T. W.
Caledonian Railway Company.
California State Mining Bureau.
Cambridge Philosophical Society.
Canadian Government Railways.
Canadian Institute.
"Canadian Magazine, The."
Canadian Society of Civil Engineers.

Canterbury College (University of New Zealand).
Carpmael, E., M.A.
Carruthers, Rev. G. T., M.A.
Cay, W. D.
"Centralblatt der Bauverwaltung."
Centralbureau fur Meteorologie und Hydrographie im Grossherzogthum, Baden.
Charnock, G. F.
Chatterton, A.
Chemical Society.
Chesterfield and Midland Counties Institution of Engineers.
Chicago, Milwaukee and St. Paul Railway Company.
Chief of Engineers, U.S. Army.
Chief Signal Officer, U.S. Army.
Chinese Customs' Office.
Churchill, C. & Co.
City and Guilds of London Institute.
City of London College.
Civil and Mechanical Engineers' Society.
Clark, D. K.
Cleveland Institution of Engineers.
Cliff, J. and Sons.
Club de Engenharia.
Codrington College, Barbadoes.
Colladon, Prof. D.
College of Agriculture, Downton.
College of Preceptors.
Collegio degli Architetti ed Ingegneri in Firenze.
Collegio degli Ingegneri ed Architetti in Milano.
Collegio degli Ingegneri ed Architetti in Palermo.
"Colliery Engineer, The."
"Colliery Guardian, The."
Collignon, E.
Collingwood, F.
Collins, A. E.
Collins, H. R.
Colman, Hon. N. J.
Colonial Museum, New Zealand.
Colonial Secretary's Office, Cape Town.
Comité des Forges de France.
Companhia de S. Christovão.
Conservatoire Nationale des Arts et Métiers.
"Contract Journal, The."
Cooper Union for the Advancement of Science and Art.
Cordemoy, C. de.
Cordemoy, J. de.
Cornaglia, P. A.
Cornell University, U.S.A.
Cornes, C.
Corthell, E. L.
Cossoux, L.
Coward, C. A.
Crimp, W. S.
Croes, J. J. R.
Crosby Brothers, Limited.
Cunningham, G. C.
Cuppari, G.
"Czasopismo Techniczne."

D.

Daft Electric Light Company.
Dawson, W. and Sons.
Deacon, G. F.
Deas, J.
Dempsey, W.
Denison, S. & Son.
Denny, Mrs. W.
Department of Mines and Water Supply, Victoria.

Department of Public Works, Chicago.
Department of Science and Art.
Department of State, U.S.A.
Department of the Interior, U.S.A.
"Deutsche Bauzeitung."
Devon and Exeter Albert Memorial Museum, Schools of Science and Art, and Free Library.
Devonshire, E.
Dick, Kerr & Co.
Director General of Telegraphs, India.
Director of the Mint, U.S.A.
Donaldson, W. M. A.
Doulton & Co.
Dowson, J. E.
Duffy, M. C. and Son, Limited.
Duluth Chamber of Commerce.
Durand-Claye, Madame A.
Durham College of Science.
Durham University.
Dwelshauvers Dery, V.
Dyckerhoff and Sohne.

E.

East India Association.
École Polytechnique Suisse.
École Spéciale d'Architecture.
École Spéciale d'Industrie et des Mines du Hainaut.
Edinburgh University.
Egleston, Prof. T.
Eiffel, G.
"Electrical Engineer, The."
Electrical Power Storage Company, Limited.
"Électricien, L'."
Engine Boiler and Employers' Liability Insurance Company, Limited.
Engineer Department, U.S. Army.
"Engineer, The."
"Engineering."
"Engineering and Building Record and Sanitary Engineer."
Engineering Association of New South Wales.
"Engineering News."
Engineers' Club of Philadelphia.
Engineers' Society of Western Pennsylvania.
Ewing, Prof. J. A., B.Sc., F.R.S.
Executors of the late Sir William Siemens.

F.

Farmiloe, G. and Sons.
Field, R., B.A.
Firth College, Sheffield.
Forcheimer, Prof. Dr.
Fordham, H. G.
Forrest, J. (Secretary).
Fothergill, J. R.
Fowler, A. M.
Fowler, W. H., Wh.Sc.
Francis, J. B.
Franklin Institute.
Franzius, L.
Free Public Libraries of the United Parishes of St. Margaret and St. John the Evangelist, Westminster.
Furness Railway.

G.

Galloway, W.
Ganga-Ram, Rai Bahadur L.
Garcia, Don D.
"Gas and Water Review, The."
Gas Institute.
"Génie Civil, Le."
Geological and Natural History Survey of Canada.
Geological Society of London.
Geologists' Association.
Gibbs, L.
Gilbert, J. H., M.A., LL.D., F.R.S.
"Giornale del Genio Civile."
Glasgow and West of Scotland Technical College.
Glasgow University.
Glenfield Company, Limited.
Glover, W. and Sons.
Gobert, A.
Gogorza, A. A. de.
Goodall, J.
Gordon, H. A.
Government Observatory, New South Wales.
Government of Bengal.
Government Statist of Victoria.
Government Telegraph Department, India.
Grafton & Co.
Graham, G.
Grantham, R. B.
Gray, M.
Gray, T.
Great Northern Railway Company.
Green, T. and Son, Limited.
Greenwood, Capt. W. N.
Guest and Chrimes.

H.

Hall, A. F.
Hall, W. H.
Hallett, H. S.
Halpin, D.
Hamilton, W.
Harpers, Limited.
Hartley Institution.
Hawkins, E. J.
Hayter, Hon. H. H.
Haywood, Lieut.-Col. W.
Hennessy, Prof. H., F.R.S.
Henriques, C. Q.
Hering, R.
Herschel, C.
Hett, C. L.
High Commissioner for the Dominion of Canada.
Hill, L. M.
Hill, W.
Hodgetts, E. A. B.
Homan, E.
Home Office.
Hongkong Observatory.
Huber, J. L.
Huet, A.
Hughes, H.
Hughes, H. W.
Humphrys, N. H.

I.

"Illustrated Naval and Military Magazine."
Imperial Russian Technical Society.
Imperial Stone Company, Limited.
Imperial University of Japan.
Incorporated Law Society.
India Office.

"Indian Engineer, The."
"Indian Engineering."
Indiana Society of Civil Engineers and Surveyors.
"Industria, L'."
"Industrie Moderne, L'."
Ingegneria Civile e le Arti industriali, L'."
Ingeniors Forening.
Institute of British Architects.
Institute of Patent Agents.
Institution of Engineers and Shipbuilders in Scotland.
Institution of Mechanical Engineers.
Institution of Naval Architects.
Instituto Polytechnico Brazileiro.
"Iron."
"Iron and Coal Trades Review."
Iron and Steel Institute.
Isherwood, B. F.

J.

Jackson, W.
Jamieson, Prof. A., F.R.S.E.
Jaques, Lieut. W. H.
Jeans, J. S.
Jefferiss, T.
Jennings, G.
Jones, C.
Jordan, C. H.
'Journal des Travaux Publics."
Judson, W. P.

K.

K. B. Academie der Wissenschaften in Munchen.
K. K. technische Hochschule in Wien.
K. Polytechnikum Stuttgart.
K. sachsische Bergakademie, Freiberg.
K. sachsisches Polytechnikum, Dresden.
K. technische Hochschule, Aachen.
K. technische Hochschule, Berlin.
K. technische Hochschule, Hannover.
Kalakoutsky, Gen. N.
Keefer, T. C.
Keith, J.
Keller, Prof. K.
Kelly & Co.
Kemna, A.
Kempe, H. R.
Kennedy, J.
Kenward, J.
Kew Observatory.
King, P. S.
King's College, London.
King's College, Windsor, Nova Scotia.
Knoke, J. O.
Koninklijk Instituut van Ingenieurs.
Kreuter, F.

L.

Lascelles, W. H. & Co.
Lass, A.
Lawes, Sir J. B., Bart., LL.D., F.R.S.
Latham, B.
Lavalard, E.
Leavitt, E. D., Jun.
Le Chatelier, H.
Le Chatelier, L.
Leeds Free Public Library and Museum.

Lehigh University.
Leigh, R. K.
Leverich, G.
Light-House Board, U.S.A.
Lincoln School of Science.
Lindley, W. H.
Liverpool Engineering Society.
Lloyd, B. S. & Co.
Lockwood, C. and Son.
Longridge, J. A.
Lovegrove, J.
Luiggi, L.
Lunt, J.

M.

Macfarlane, W. & Co.
McGill College and University, Montreal.
McIntyre, J. J.
McMinn, T. J.
Madras University.
Magyar Mernok.
Mair, J. G.
Malo, L.
Manchester Association of Engineers.
Manchester Literary and Philosophical Society.
Manchester Steam Users' Association.
Manchester Technical School.
Manning, R.
Marié, G.
Maritime Canal Company of Nicaragua.
Marsden, H. R.
Marshall, W. P.
Mason Science College, Birmingham.
Massachusetts Institute of Technology.
Massing, Col.
Master Car-Builders' Association.
Mathews, E. D.
Matthews, W.
Meade, T. de C.
"Mechanical Progress."
Mechanics' Institute of San Francisco.
Melbourne University.
Melhuish, T. W.
Melik-Beglar, J. D.
Merchant, S. L.
Merchant Venturer's School, Bristol.
Meteorological Commission, Cape of Good Hope.
Meteorological Office, India.
Meteorological Office, London.
Michaelis, Dr. W.
Middlesex Natural History and Science Society.
Middleton, R. E.
Midland Institute of Mining, Civil and Mechanical Engineers.
Military Service Institution, U.S.A.
Mines Department, New Zealand.
Mines Office, Hobart, Tasmania.
Mining Association and Institute of Cornwall.
Mining Institute of Scotland.
Minister, G. & Co.
Ministère de l'Agriculture de l'Industrie et des Travaux Publics, Bruxelles.
Ministère de la Marine et des Colonies, Paris.
Ministère des Chemins de Fer, Postes et Télégraphes, Bruxelles.

Ministère des Travaux Publics, Paris.
Ministry of Public Works, Berlin.
Mitchell Library, Glasgow.
"Modern Light and Heat."
Mohr, E.
Moncrieff, Col. Sir C. C. S., K.C.M.G., C.S.I., R.E.
"Moniteur Industriel, Le."
"Monthly Weather Review, U.S.A."
Moore, R.
Mordecai, G.
Morse, S.
Muller, E.
Muller, Dr. F. C. G.

N.

Natal Harbour Board.
National Association of British and Irish Millers.
National Association of Builders.
National Boiler Insurance Company, Limited.
"National Car and Locomotive Builder."
National Railway Publication Company, New York.
Netherlands Legation.
New Zealand University.
Newall, Maj.-Gen. D. J. F., R.A.
Nisbet, W. D.
Norman, J. H.
Norske Ingeniör og Architekt Förening.
North of England Institute of Mining and Mechanical Engineers.
North-East Coast Institution of Engineers and Shipbuilders.
"Northwestern Miller."

O.

O'Connor, C. Y.
Oesterreichischer Ingenieur- und Architekten-Verein.
Office of the Australian Irrigation Colonies.
Office of the High Commissioner for Canada, London.
Office of the Inspectorate-General of Chinese Maritime Customs.
Office of the Light-House Board, U.S.A.
Oficina Meteorológica Argentina.
Olive, W. T.
Ordnance Department, U.S.A.
Orell, F. & Co.
Osterrieth, A.
Owens College, Manchester.

P.

Parker, W.
Parry, J.
Parry, J. W.
Patent Office.
Patent Victoria Stone Company, Limited.
Peabody Institute.
Pennsylvania Railroad Company.
Périssé, S.
Perley, H. F.
Perry, Prof. J., M.E., D.Sc., F.R.S.
Perry, Rev. S. J., S.J., D.Sc., F.R.S.
Pharmaceutical Society of Great Britain.
Philippe, L.
Philipson, W.

Phillips, G.
Philosophical Society of Glasgow.
Physical Society of London.
Pinheiro, A. A. F.
Pole, W., F.R.SS. L. & E. (Hon. Sec.).
"Politecnico, Il."
Pontifex and Wood, Limited.
Porter, J. H. & Sons.
Praschkauer, M.
Prinetti, T.
Privy Council Office.
"Przegląd Techniczny."
Public Free Libraries, Borough of Bradford.
Public Free Libraries, Manchester.
Public Libraries, Newcastle-upon-Tyne.
Public Works Department, Allahabad.
Public Works Department, Bombay.
Public Works Department, Wellington, N.Z.

Q.

Queen's College, Belfast.
Queen's College, Cork.
Queen's College, Galway.
Queen's College and University, Kingston, Canada.
Queensland Branch of the Royal Geographical Society of Australasia.

R.

Radcliffe Library, Oxford University Museum.
Raddi, A.
"Railroad and Engineering Journal."
"Railway Engineer, The."
"Railway Master Mechanic."
Ransome, J. S.
Rea, S.
Reade, T. M.
Reale Accademia dei Lincei.
Reale Istituto Lombardo.
Regio Instituto Tecnico Superiore di Milano.
Rendrock Powder Company.
Rensselaer Society of Engineers.
"Revista de Engenharia."
"Revista de Obras Publicas, Lisbon."
"Revista de Obras Públicas, Madrid."
"Revista dos Construtores."
"Revue générale de l'Architecture et des Travaux Publics."
"Revue générale des Chemins de Fer."
"Revue Industrielle."
"Revue Universelle des Mines."
Richards, Admiral Sir G. H., K.C.B., F.R.S.
Riedler, Prof. A.
Riggenbach, N.
Riley, C. V.
Ritter, Prof. Dr. A.
Robert, J.
Robey & Co.
Robinson, J.
Roustan, Capt. A.
Rowan, F. J.
Royal Agricultural College, Cirencester.
Royal Agricultural Society of England.
Royal Artillery Institution.
Royal College of Science for Ireland.

Royal College of Surgeons of England.
Royal Colonial Institute.
Royal Cornwall Polytechnic Society.
Royal Dublin Society.
Royal Engineers' Institute.
Royal Geographical Society.
Royal Geological Society of Ireland.
Royal Indian Engineering College.
Royal Institute of British Architects.
Royal Institution of Great Britain.
Royal Irish Academy.
Royal Meteorological Society.
Royal Naval College, Greenwich.
Royal Observatory, Greenwich.
Royal Scottish Society of Arts.
Royal Society of Edinburgh.
Royal Society of London.
Royal Society of New South Wales.
Royal Society of Victoria.
Royal Statistical Society.
Royal United Service Institution.
Royal University of Ireland.
Ruhlmann, Dr. M.
Ruttan, H. N.
Ryan, R. H.

S.

St. Andrew's University.
St. David's College, Lampeter.
Sala, P. P. de la.
Sang, E., LL.D.
"Sanitary Engineering."
Sanitary Institute of Great Britain.
Sassoon Mechanics' Institute.
Schilling, Dr. E.
Schreiber, C.
Schwebelé, E.
Science and Art Department.
Scott, Maj.-Gen. A. de C.
Scott, J.
Seaver, R.
Seismological Society of Japan.
Sellers, Prof. C. E. D.
Sellon, S. P. W. D'Alte.
Shaw, Capt. E. M.
Simons, W. & Co.
Slaby, Prof. Dr.
Smith, G. & Co.
Smith, J. H.
Smith, Prof. R. H.
Smith, W. & Sons.
Smithsonian Institution.
Sociedad Cientifica Argentina.
Sociedad de Ingenieros Civiles de la República Argentina.
Società degli Ingegneri e degli Industriali di Torino.
Société des Ingénieurs civils de Paris.
Société industrielle de Mulhouse.
Société nationale des Sciences naturelles et mathématiques de Cherbourg.
Société scientifique industrielle de Marseille.
Society for the Abolition of Vivisection.
Society of Architects.
Society of Arts.
Society of Chemical Industry.
Society of Engineers.
Society of Telegraph-Engineers and Electricians.

South African Philosophical Society.
South Staffordshire and East Worcestershire Institution of Engineers.
South Wales Institute of Engineers.
Southern District Association of Gas Engineers and Managers.
Sowerby, W.
Stanley, W. F.
Star Iron Tower Company.
State Board of Health of Massachusetts.
State Board of Health of New York.
State Board of Health of Wisconsin.
Stayton, G. H.
Stearns, F. P.
"Stevens Indicator, The."
Stidder, Davis & Co.
Stone, J. & Co.
Strobel, C. L.
Strype, W. G.
Sugg, W. & Co., Limited.
Surgeon-General, U.S. Army.
Surveyor-General of India.
Surveyors' Institution.
Sutter, A.
Swan, C. H.
Symons, G. J., F.R.S.

T.

Taite, J. C.
Technical Society of the Pacific Coast.
Technische Hochschule zu Karlsruhe.
Technische Staatslehranstalten zu Chemnitz.
"Telegraphic Journal and Electrical Review."
Thomason Civil Engineering College.
Thomson, Sir W., LL.D., F.R.SS. L. & E.
Thropp, J.
Thrupp, E. C.
Thwaites, W., M.A.
Tidman, E.
Traill, T. W.
Tratman, E. E. R.
Trautwine, J. C., Jun.
Trélat, Prof. E.
Trevail, S.
Trigonometrical Branch Office, Survey of India.
Tripp, W. B.
Tyler, H. & Co.
Tyler, Capt. Sir H. W., M.P., late R.E.
Tyndall, J., LL.D., F.R.S.

U.

Unione Tipografico - Editrice Torinese.
United States Coast and Geodetic Survey.
United States Department of Agriculture.
United States Geological Survey.
United States Military Academy.
United States Naval Institute.
United States Navy Department.
Université de Gand.
Université de Liége.
University College, Bristol.
University College, Dundee.
University College, Liverpool.
University College, London.
University College, Nottingham.

University College of South Wales and Monmouthshire.
University of California.
University of Michigan.
University of Sydney.
University of Toronto.
University of Trinity College, Toronto.
Unwin, Prof. W. C., B.Sc., F.R.S.
Usill, G. W.

V.

Vallot, H.
Valon, W. A.
Varley, S. A.
Vauthier, L. L.
Venezuelan Consulate.
Verein deutscher Cement-Fabrikanten.
Verity, B. & Sons.
Vernon-Harcourt, L. F., M.A.
Victoria University, Canada.
Victoria University, Manchester.
"Victorian Engineer, The."
Victorian Railway Commissioners.
Vogan, H. S.

W.

Walker, T. A.
Waller, G. & Co.
Walton, J. B.
Waring, F. J.
Warner, W.
Water Commissioners, City of Taunton, Mass.
Waterlow Bros. and Layton, Limited.
Watkins, R.
Watson, R.
Wears, W. G.
Weedon, J. F.
Werner, E. A.
Westinghouse Brake Company, Limited.
Weston, E. B.
Weyrauch, Dr. J. J.
Wheeler, W. H.
Whitaker, W., B.A., F.R.S.
Wiggers, M.
Wiley, J. & Sons.
Willett and Pashley.
Williams, B. R. W.
Williams, M. J. M., M.A.
Willing & Co., Limited.
Wilson, J. M.
"Wiltshire Rainfall."
Wimshurst, J.
Winkler, Prof. H.
Witz, Dr. A.
"Wochenblatt fur Baukunde."
Wolff, A. R.
Woodhouse and Rawson.
"Woodite" Company, Limited.
Worth, R. H.

Y.

Yorkshire Boiler Insurance and Steam Users' Co., Limited.
Yorkshire College, Leeds.

Z.

Zimmermann, Dr. H.

The Donations to the Library Fund were as under :—

	£	s	d
Argyle, J.	1	1	0
Benson, J. J. B.	2	2	0
Burgh, E. M. de	4	0	0
Burke, J. M.	2	2	0
Clement, L. M.	5	0	0
Conceição, J. M.	5	0	0
Cook, G. L.	4	4	0
Deane, H.	5	0	0
Denison, G. C.	5	0	0
Dougall, A., Jun.	1	1	0
Dowley, E. P.	2	2	0
Eckersley, W. A.	2	2	0
Gill, J. (Fulham)	1	1	0
Goslett, C. A.	1	1	0
Gregson, H. B.	1	1	0
Griffiths, T.	2	2	0
Housden, W. P.	5	5	0
Jack, A. J.	2	2	0
Jones, W. G.	1	1	0
Kershaw, F. W.	1	1	0
Kingsford, H.	2	2	0
Lefébure, E. E.	1	1	0
Mann, Maj.-Gen. J. R.	1	11	6
Carried forward	£58	2	6
Brought forward	58	2	6
Morcom, A.	2	2	0
Morris, W. R.	2	2	0
Morse, A.	5	0	0
Mylne, H. C.	5	0	0
Napier, Hon. E. H. S.	5	0	0
Parkinson, J.	1	1	0
Richards, T.	5	0	0
Roberts, R. G. S.	2	0	0
Rowling, F. H.	1	1	0
Scholefield, E. E.	2	2	0
Schram, J. R.	5	5	0
Sheldon, F.	1	11	6
Silk, A. E.	3	3	0
Silva, D. S. de S.	10	0	0
Utley, S.	5	5	0
Ward, J.	2	2	0
Warren, J. A.	1	1	0
Wasey, G. K.	5	5	0
Watson, W.	5	0	0
Webster, C.	1	1	0
Wilkinson, J. P.	1	1	0
Williamson, J. R. H.	2	2	0
	£131	7	0

LIST OF PAINTINGS
IN THE POSSESSION OF
THE INSTITUTION OF CIVIL ENGINEERS

SEPTEMBER 1889.

Title.	Painter
Portrait of T. Telford	S. Lane.
,, J. Walker	J. P. Knight, R.A.
,, Sir John Rennie	James Andrews.
,, Sir W. Cubitt.	
,, Joshua Field	James Andrews.
,, James Simpson.	
,, Robert Stephenson	Henry Phillips.
,, Joseph Locke	Sir Francis Grant, P.R.A.
,, John Hawkshaw	T. Collins.
,, J. R. McClean	Charles Landseer, R.A.
,, John Fowler	J. E. Millais, R.A.
,, C. H. Gregory	John Collier.
,, Thomas Hawksley	H. Herkomer, A.R.A.
,, T. E. Harrison	W. W. Ouless, R.A.
,, Sir Fredk. Bramwell	F. Holl, R.A.
,, Sir George B. Bruce	W. M. Palin.
,, I. K. Brunel	J. C. Horsley, R.A.
,, Joseph Miller	W. Boxall, R.A.
,, Sir W. Siemens	Rud. Lehmann.
,, T. Brassey	J. B. Halle.
,, Gen. Alex. Wilson.	
,, Charles Manby	Sidney Hodges.
,, Matthew Boulton.	
,, James Brindley	F. Parsons.
,, Joseph Huddart	Wildman, after Hoppner.
,, W. Jessop	Edwin Williams.
,, John Rennie (Sen.)	Raeburn.
,, George Stephenson	? Briggs or Lucas.
,, John Smeaton	Wildman, after Gainsborough.
,, Robert Stephenson	J. Lucas (for Br. Bridge group).
,, William Whidbey	J. Ponsford.
Menai Suspension Bridge.	
Grimsby Docks	Carmichael.
Old Westminster Bridge	Scott.
Conference of Engineers at the Britannia Bridge	J. Lucas.
Pont-y-Cycylte Aqueduct.	

Water-Colours.

Woolwich Dock, 1841.
Hanwell Viaduct.

OFFICERS, 1889-90.

COUNCIL:

President.

Sir JOHN COODE, K.C.M.G.

Vice-Presidents.

George Berkley,
Harrison Hayter,
Alfred Giles, M.P.,
Sir Robert Rawlinson, K.C.B.

Members.

William Anderson (*Erith*), D.C.L.,
Benjamin Baker,
John Wolfe Barry,
Edward Alfred Cowper,
Sir James Nicholas Douglass, F.R.S.,
Sir Douglas Fox,
J. Clarke Hawkshaw, M.A.,
Charles Hawksley,
Sir Bradford Leslie, K.C.I.E.,
George Fosbery Lyster,
James Mansergh,
William Henry Preece, F.R.S.,
Sir Edward James Reed, K.C.B., F.R.S., M.P.,
William Shelford,
Francis William Webb.

⁂ *This Council will continue till June* 1890.

HONORARY COUNCILLORS:

Past-Presidents.

Sir John Hawkshaw, F.R.S.,
Sir John Fowler, K.C.M.G.,
Sir Charles Hutton Gregory, K.C.M.G.,
Thomas Hawksley, F.R.S.,
George Robert Stephenson,
William Henry Barlow, F.R.S.,
James Abernethy, F.R.S.E.,
Lord Armstrong, C.B., LL.D., D.C.L., F.R.S.,
Sir James Brunlees, F.R.S.E.,
Sir Joseph Wm. Bazalgette, C.B.,
Sir Frederick J. Bramwell, *Bart.*, D.C.L., F.R.S.,
Edward Woods,
Sir George Barclay Bruce.

OFFICERS:

Auditors.

Alexander McKerrow,
Robert Whill

Treasurer.

Hugh Lindsay Antrobus.

Honorary Secretary.

William Pole, F.R.SS. L. & E.

Secretary.

James Forrest.

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 2403.*)

"Experiments on a Steam-Engine, the Cylinder of which was heated externally by Gas-flames."

By BRYAN DONKIN, Jun., M. Inst. C.E.

IN the following experiments an attempt has been made to determine how far cylinder-condensation can be prevented, and an economy of steam realized by heating an engine cylinder externally by gas-flames, so as to raise its temperature considerably.

The engine was of the horizontal single-cylinder type. Diameter of cylinder, $8\frac{7}{16}$ inches; stroke, 14 inches. It was coupled direct to a rotary gas exhauster used merely to pump air so as to absorb the power. One set of experiments were made non-condensing, and one set condensing. In the latter case communication was made with the condenser of a factory engine, so that the air-pump discharge of the experimental engine could not be measured. The feed-water was carefully measured in all the trials, and indicator diagrams were taken frequently from both ends of the cylinder.

The arrangement of the gas-jets was necessarily somewhat imperfect; but every care was taken to ensure accuracy in recording the results. Several experiments were made both with and without the condenser, and with and without the gas-flames. When using the gas-flames the quantity of gas burned was varied. The Bunsen burners were placed quite close to the cylinder externally, and the flames reached about halfway round the cylinder. External radiation was prevented, as far as possible, by sheets of asbestos, the products of combustion passing away through holes left in these sheets. The expansion was constant in all the experiments, as there was no separate expansion-valve.

Results of the Experiments.—These are given in the Tables below. It will be seen that the temperature of the cylinder wall when the gas-flames were used was generally much above that of the steam admitted.

There is a decided economy of steam when the gas-flame jacket is used, but against this must be set the cost of the gas used. This will vary in different localities, and the commercial gain will be the difference of cost of the fuel saved and the gas used.

Since these experiments were made a better mode of burning the gas has been adopted.

Professor Dwelshauvers Dery, of the University of Liége, was much interested in this novel way of heating the cylinder, and, at his request, copies of the results were sent to him. He has carefully analyzed these results and compared them with experiments in which two other ways of reducing cylinder-condensation were used. In Mr. Willans' experiments the amount of cylinder-condensation, reckoned per indicated HP., is reduced by increasing the speed of the engine. In Mr. Hirn's experiments the condensation is diminished by superheating the steam. The comparison of the economy obtained by these three methods is instructive.

TABLE I.—SUMMARY of EXPERIMENTS on a 6-HP. NON-CONDENSING STEAM-ENGINE, WITH and WITHOUT GAS-FLAME JACKET, at BERMONDSEY, 1888.

—	—	Without Gas-Jacket.	With Gas-Jacket.		
	Experiment . . .	No 3	No. 6	No. 9	No. 8
	Date, 1888 . . .	July 26	July 28	July 31	July 31
	Duration . hours	4	4	3	3
Feed-water .	Feed-water per I HP. per hour . . . lbs	44·4	34·1	33·8	34·8
I HP. . .	I HP. by diagrams .	6·26	6·17	6·33	6·31
Ordinary London gas	Gas burnt in Bunsen burner per hour cub. feet	0	49	40	35
Temperature	External temperature of cyl. walls at top . . ° Fah.	248	414	..	336
Steam - pressure above atmosphere	Boiler-pressure . lbs.	35·5	35·0	35·5	34·5
	Initial pressure in cylinder ”	31·7	34·7	34·7	33·8
Speed . .	Revolutions per min. (by counter) . .	90·73	90·79	89·7	90·1
	Total revolutions .	21,776	21,790	16,147	16,218
Steam from diagram .	Steam per I.HP. per hour calculated from diagrams at $\frac{8}{10}$ths stroke . lbs.	35·87	34·42	34·37	..
	Percentage of steam used shown on diagrams at $\frac{8}{10}$ths stroke	80	101	$101\frac{3}{4}$	..

CHIEF RESULTS OF THE EXPERIMENTS.

TABLE I, *with and without gas, non-condensing.*—Comparing experiments No. 3 with No. 9, there is an economy of 24 per cent. in feed-water per indicated HP. per hour, and this with practically the same pressure of steam, power, speed, and expansion. It will be noticed that the external temperature of the cylinder-walls was much greater with the gas burning than without. The initial pressure of steam of the indicator diagrams was also about 3 lbs. greater, say 10 per cent. with the gas than without. As to the steam calculated from the diagrams at $\frac{8}{10}$ of the stroke, 80 per cent. only of the total steam supplied appeared in experiments without the gas-flame jackets, and 20 per cent. was missing; while on the other hand, with gas-jackets on, the diagrams showed that at $\frac{8}{10}$ of the stroke, all the feed-water was present as steam, there being no missing quantity.

TABLE II.—SUMMARY of EXPERIMENTS on SAME 6-HP. STEAM-ENGINE, but CONDENSING, WITH and WITHOUT GAS-FLAME JACKET, 1888.

—	—	No Gas-Jacket.	With Gas-Jacket	
	Experiment	No. 4	No. 3.	No. 2
	Date, 1888	August 9	August 9	August 8
	Duration . . . . hours	3	3	3
Feed-water .	Feed-water per HP. per hour . . . . lbs.	38·5	30·7	30·3
I.HP. . .	I HP. by diagrams . . .	5·61	6·05	5·47
Ordinary London gas	Gas burnt per hour in Bunsen burners . . cub. feet	0	35	28
Temperature	External temperature of cyl. walls taken at top . . . . ° Fah.	213	239	240
Steam-pressure above atmosphere	Boiler-pressure.	35·0	34·5	34·5
	Initial pressure in cylinder, lbs	14·8	15·3	13·2
Speed . .	Revolutions per minute (by counter)	92·27	92·66	90·16
	Total revolutions	16,610	16,680	16,230
Steam from diagram .	Steam per I HP. per hour calculated from diagram at $\frac{8}{10}$ths stroke lbs.	28·3	27 3	27·3
	Percentage of steam used shown on diagrams at $\frac{8}{10}$ths stroke	73½	89	90

TABLE II, *with and without gas, condensing.*—Comparing experiment No. 4 with No. 2 there is an economy due to the gas-flame jacket of 21 per cent. in feed-water per indicated HP. per hour, with about the same pressure of steam, power, speed, and expansion.

The temperature of the external cylinder-walls was greater with the gas.

The initial pressure of steam was also greater with the gas. In the steam calculated from the diagrams at $\frac{8}{10}$ of the stroke, 73 per cent. only was shown on the diagrams in the experiments without the gas-flame jacket.

In the experiments with the gas-flame jacket 90 per cent. of the total steam used was shown on the diagrams, or a diminution of condensation of 17 per cent.

Comparing the two sets of experiments, Table I and Table II, the jacket gives a rather greater effect in the non-condensing set than in the condensing. The experiments made with increased quantities of gas, show that after the cylinder metal had been raised to a certain temperature, the extra quantity of heat seemed to have no beneficial effect whatever. Probably the extra heat was partly radiated externally, and partly passed away with the exhaust.

A few trials were made at 45 revolutions, and there was still an economy due to the gas-flame jacket, but not nearly so marked as at 90 revolutions.

(*Paper No. 2403a.*)

"Investigation of the Heat-Expenditure in Steam-Engines, especially with reference to Methods of Diminishing Cylinder-Condensation."

By Professor DWELSHAUVERS DERY, of Liége University.

(Translated by Professor W. C. UNWIN, F.R.S., M. Inst. C.E.)

1. Out of the twenty-three trials of a steam-engine carried out by Mr. Bryan Donkin, jun., nine of them with and fourteen without condensation, the Author has selected four for study, two made with condensation and two without condensation. They will be numbered and referred to thus:—

I. With condensation, with gas-flame jacket, made on August 8th. No. 2 of Donkin.
II. With condensation, without gas-flame jacket, made on August 9th. No. 4 of Donkin.
III. Without condensation, with gas-flame jacket, made on July 31st. No. 9 of Donkin.
IV. Without condensation and without gas-flame jacket, made on July 26th. No. 3 of Donkin.

The calculations were made in French measures and the results reduced to English measures. The Author afterwards studied directly in English measures the trial with condensation and gas-flame jacket of August 9th, numbered 3 in Mr. Donkin's Table. It is referred to in this memoir as I *bis*, since it was made in conditions nearly identical with those of No. I above. Lastly, as the results of No. III, without condensation and with gas-flame jacket, seemed to merit special attention, the calculations were repeated in English measures, the results being identical with those previously obtained.

2. *Method of calculation.*—The calculations were made by the method published in the 'Revue Universelle des Mines' (Vol. viii., September and October, 1880), deduced from the practical theory of Hirn. The results are exhibited by the Author's "Diagram of Exchanges of Heat between the Steam and Walls

of the Cylinder," explained in a memoir of January, 1888, to the Société Industrielle de Mulhouse. Of this memoir Mr. Donkin gave a sketch in 'Engineering,' July 27th, 1888. The diagram was also described in the correspondence on Mr. Willans's Paper.[1]

The method consists in calculating from the indicator-diagram the quantities of heat in thermal units which the steam acting in the cylinder loses: 1stly, in doing external work designated by T; 2ndly, in heating the cylinder-sides, a quantity designated by R, and which constitutes what is here termed the heat exchange. If the calculation leads to a negative value of R, the heat, instead of going from the steam to the metal, is restored by the metal to the steam; in other words, heat is gained instead of being lost.

The heat corresponding to the absolute external work of the forward stroke is borrowed from the steam, which consequently loses it. As this is considered positive, it is necessary to treat as negative the heat restored to the steam by the cylinder sides. Similarly the work of the back-pressure in the return-stroke is negative and corresponds to heat received by the steam.

3. *Notation employed.*—For shortness subscript letters are employed to indicate the periods of the stroke for which the phenomena are considered:—

a for the period of admission;
d ,, ,, expansion;
e ,, ,, exhaust;
c ,, ,, compression.

The following statement makes this clear:—

During admission the steam loses $T_a + R_a$ in external work and in heating the metal.
,, expansion ,, ,, $T_d + R_d$,, ,, ,,
,, exhaust ,, gains $T_e + R_e$ by external work and cooling of the metal.
,, compression ,, ,, $T_c - R_c$ by external work and heating of the metal.

4. *Graphic representation of the quantities of heat.*—The quantities of heat T being proportional to the work done by or on the steam can be measured directly from the indicator-diagram. The

---

[1] Minutes of Proceedings Inst. C.E., vol. xciii.

quantities of heat-exchange, R, can be calculated from the data of the trial, and especially from those shown by the indicator-diagram. The quantities of heat T are given on the indicator-card by areas. Hence the idea occurred to the Author to represent the heat-exchange R in the same way, and to the same scales, so that the two diagrams for T and R should be superposed and comparable.

The volume described by the piston in one stroke is represented on the indicator-diagram by a length on the axis of abscissas. From that can be obtained the horizontal length h which corresponds to 1 cubic foot. The scale of the indicator gives the length measured vertically which represents 1 lb. per square inch. Dividing this by 144 is obtained the length v, representing 1 lb. per square foot. Hence an area having h for base and v for height represents 1 foot-lb. of work. 772 times that area is the area which represents a thermal unit, or for the present purpose the unit of areas.

Let A B D E F C A, Plate 2, Fig. 1, be an indicator-diagram, in which

A is the beginning of admission;
B ,, ,, the forward stroke;
D ,, ,, expansion;
E ,, ,, release;
F ,, ,, the return stroke;
G ,, ,, compression.

The number of times the area d D E e d contains the unit of areas is that which is denoted by T_d. Similarly the area c C A a c measured in the same units is T_c. As to admission, it consists of two parts; anticipating a A B b a = T''_a and b B D d b = T'_a and the difference $T'_a - T''_a = T_a$. In the same way for exhaust, let e E F f e = T'_e and f F C c F = T''_e. Then $T''_e - T'_e = T_e$.

The positive external work which Hirn calls the absolute work is the area b B D E F f b = T_f. Hence $T_f = T'_a + T_d + T'_e$.

If from the positive work, the work b B A C F f b = $T''_a + T_c + T''_e$ is subtracted, we get the indicated work $T = (T'_a + T_d + T'_e) - (T''_a + T_c + T''_e) = (T_a + T_d) - (T_e + T_c)$.

Let V_a cubic feet be the volume described by the piston during admission $= bd + ba$;
V_d ,, ,, ,, ,, expansion $= de$;
V ,, ,, ,, ,, exhaust $= ef + fc$;
V_c ,, ,, ,, ,, compression $= bf$.

If the pressure were constant during admission and $= p_a$ lbs. per square foot, the work done would be $p_a V_a$ foot-lbs., or $\frac{p_a V_a}{772}$ thermal units $= T_a$. Hence $p_a = 772 \frac{T_a}{V_a}$. The area of the rectangle having V_a for base and p_a for height, represents to the scale of the diagram the heat borrowed from the steam to do external work during admission.

5. *Drawing the mean diagram of exchanges.*—Suppose R_a the heat-exchange during admission is known; then the height r_a of a rectangle, which, having also V_a for base and $772\ R_a$ for area, is given by the equation—

$$r_a = 772 \frac{R_a}{V_a}.$$

Then r_a represents the heat given by the steam to the cylinder-walls, to the same scale in lbs. per square foot, as p_a represents the heat expended in doing external work. Similarly for the other periods of the stroke, when R_a, R_d, R_e, R_c are known, the heights of the rectangles representing the heat-exchanges are -

$$r_a = 772 \frac{R_a}{V_a};\ r_d = 772 \frac{R_d}{V_d};\ r_e = 772 \frac{R_e}{V_e};\ r_c - 772 \frac{R_c}{V_c}.$$

All the rectangles which have, to the same scale as the indicator-diagram, V_a, V_d, V_e, V_c for bases, and r_a, r_d, r_e, r_c for heights, constitute what the Author calls the mean diagram of exchanges of heat.

6. *Diagram of absolute work and of absolute loss by the metal.*—It is useful to add two other rectangles to give a complete idea of the thermal phenomena in steam-engine cylinders. The absolute work or positive external work during the stroke is represented by the area $a\,A\,B\,D\,E\,F\,f\,a = T_f$ thermal units. This can also be represented by a rectangle having V_f for base and a height given by the equation—

$$t_f = 772 \frac{T_f}{V},$$

where $T_f = T'_a + T_d + T'_e$.

Similarly the absolute loss of heat from the cylinder sides is called the sum $R_f = R_e + R_a + R_d$ of the quantities of heat exchanged while the steam is in the cylinder. Let—

$$r_f = 772 \frac{R_f}{V_f} = 772 \frac{R_c + R_a + R_d}{V_f},$$

then r_f is the height of a rectangle of base V_f equal to the volume described by the piston, the area of which represents the absolute loss of heat during the stroke. The line bounding this rectangle is marked $x\ y$ on the diagrams.

7. *Definition of the absolute loss of heat due to the cylinder-walls.*—It is important here to make a remark which justifies the term absolute loss of heat due to the cylinder-walls. Generally during compression and admission the metal receives heat, and it restores part during expansion to the steam acting in the cylinder. But during exhaust that which the metal restores is discharged from the cylinder with the steam, unutilized. This is the exchange denoted by R_e, and it represents internal radiation of the heat by the metal. There is also an external radiation which will be termed E when there is no jacket, and E − Q′ when there is a jacket. In the latter case Q′ represents the total heat which has been expended in the jacket, and of which a part E′ proceeds outwards and a part Q′ − E passes inwards to the cylinder. It is obvious that the sum of the quantities of heat received and restored by the metal while the steam is enclosed in the cylinder is equal to that of the quantities of heat which the metal has given up either to the interior of the cylinder through the agency of the steam or to the exterior air. Therefore—

$$R_f = R_c + R_a + R_d = R_e + (E - Q').$$

The last term E − Q′ may be a gain and not a loss, as happens in trial III of Donkin. In that case the jacket drove through the metal into the steam the quantity of heat Q′ − E. But even when it acts advantageously, the jacket does not always drive heat inwards. It may only preserve the steam from external radiation. This is a capital fact springing out of Mr. Donkin's experiments, but which has not previously been clearly indicated.

8. *Distinction between positive and negative quantities of heat.*—In all that concerns the diagram of exchanges the same convention is adopted as in the indicator-diagram. In the forward stroke the positive quantities of heat, that is, those which the steam loses in doing external work, are measured upwards from the line of zero pressure. In the return stroke it is the negative quantities of heat, which correspond to work done on the steam, which are

measured upwards from the line of zero pressure. The same rule is adopted for the diagram of exchanges.

Thus, in the trials I *bis*, I, II, and IV of Donkin, it is the steam which during admission yields heat to the metal. The heights r_a are therefore measured upwards from the axis of abscissæ. In these four trials, during expansion in the forward stroke, it is the metal which gives heat to the steam, so that r_d is negative and is measured downwards. In these trials during exhaust the metal gives heat to the steam. The area for the exhaust during the forward stroke is measured downwards and for the return stroke upwards. In trial III the exchange during exhaust appearing to be zero is not represented by any area. In the same trial the exchange during admission being negative, so that heat is driven through the metal and received by the steam, the area which represents it is negative and measured downwards. Lastly, in the five trials during compression, the steam yields heat to the metal, the exchange is positive, and occurring in the return stroke r is measured downwards. In the diagrams of exchange that which relates to the preadmission is not drawn, in order not to complicate the diagram. The quantity of heat corresponding to this part of the stroke has neither interest nor importance.

The area representing the absolute work done in the forward stroke is above the axis of abscissas, the corresponding quantity of heat being positive. The area which represents the loss of heat which occurs during exhaust, a negative exchange almost confined to the return stroke, is, therefore, according to the convention also above the axis of abscissas. Only in trial III in the end it is the steam which has received heat driven through the cylinder-sides, and the area representing this quantity is below the axis.

9. *Scales of the diagrams.*—Whatever the engine in question, invariably the stroke of the piston is represented by a length of 1·8 inch. The volumes described in the different periods of the stroke are given fractions of the volume described in one stroke. They are represented by lengths which are the same fractions of 1·8 inch.

Let the total heat expended in the cylinder per stroke be Q thermal units. If we also know the quantity of heat Q′ expended in the jacket, then Q + Q′ is the real total of heat expended. In the case of Mr. Donkin's trials since Q′ was not measured, the quantity Q only is calculated. (It is the total heat of the steam reckoned from 32° Fahrenheit.)

With a view of comparing the diagrams of steam-pressure and pressure equivalent to the heat-exchange for all engines, all heat quantities are referred to a well-defined unit, namely, 1179·12 thermal units. The total heat of 1 lb. of steam at 6 atmospheres, or 88·2 lbs. per square inch, which is about an average of the pressures used, is termed the weight of steam really expended, and denote by π lbs. the quantity

$$\pi = \frac{Q + Q'}{1{,}179 \cdot 12}, \text{ or } \frac{Q}{1{,}179 \cdot 12},$$

according as the jacket has furnished Q′ thermal units, or has been out of action. The ordinates of the diagram represent lbs. per square foot per lb. of steam, and they are obtained by dividing either p or r by π, according as real pressures or pressures equivalent to heat-exchanges are dealt with.

For example. In trial I, $R_a = 0 \cdot 5507$ thermal unit for $V_a = 0 \cdot 2422$ cubic foot, and $\pi = 0 \cdot 015212$ lb. Hence—

$$r_a = 772 \frac{R_a}{V_a} = 6{,}966 \text{ lbs. per square foot,}$$

$$\frac{r_a}{\pi} = \frac{6{,}966}{0 \cdot 015212} = 458{,}000 \text{ lbs. per square foot per lb. of steam,}$$

or $$\frac{458{,}000}{144} = 3{,}180 \text{ lbs. per square inch per lb. of steam.}$$

The scale of the ordinates is 1 inch per 3,470 lbs. per square inch per lb. of steam, or, what is the same thing, an inch to 499,680 lbs. per square foot per lb. of steam.

Thus the line which limits the diagram of R_a in trial I will be measured up from the axis to a height of

$$\frac{3{,}180}{3{,}470} = \frac{458{,}000}{499{,}680} = 0 \cdot 91 \text{ inch.}$$

The scale is chosen to permit the comparison of all engines however they perform.

10. *Data of the engine experimented on.*—The engine used in Mr. Donkin's trials was a double-acting horizontal engine, without a back piston-rod, and with different lead, expansion, and clearance for the two ends of the cylinder. The volumes occupied by the steam at the beginning and end of expansion, and at the beginning

and end of compression, differ much for the two strokes. In fact—

		Volumes in Cubic Feet.			
		Front End	Back End	Difference	Per cent.
Beginning of expansion	V_0	0·2561	0·3196	0·0635	22
End	V_1	0·3941	0·4452	0·0511	12
Beginning of compression . . .	V_2	0·1141	0·1454	0·0313	24
End	V_3	0·0490	0·0543	0·0053	10

It was not possible to take means or to suppose an equal amount of steam admitted to each end of the cylinder. Was it necessary, therefore, to renounce the study of such important trials giving results so remarkable? The Author preferred to adopt a reasonable hypothesis at the risk of diminishing the trustworthiness of the calculations. The two ends of the cylinder have been treated as if they belonged to two different engines and means have been taken only for the final results in drawing the diagrams. Nothing is doubtful, therefore, except the division of the steam into two quantities corresponding to the two ends of the cylinder.

11. *Mode of proceeding in studying the trials.*—For the division of the steam the following proceeding was adopted. From the pressure and volume at the end of the admission, the weight of dry steam in the cylinder has been calculated for each end of the cylinder. For example, for trial 1 *bis* of the 9th of August, it is found that these weights are respectively.—

Front end . . . 0·015110 lb $= m_o$ $M_c = 0·001537$ lb
Back ,, . . . 0·016888 ,, $= m'_o$ $M'_c = 0·001845$,,

These weights of steam have not come entirely from the boiler. Portions M_c M'_c remained in the cylinder at the moment when exhaust ended. Then the steam due to the boiler is

		Lb.
Front end	$m_1 - M_c =$	0·013573
Back ,, ...	$m'_1 - M'_c =$	0·015043
Per revolution		0·028616

But the steam delivered from the boiler was 557·4 lbs. in 16,680 revolutions, or 0·033417 lb. per revolution. That weight is divided into two portions respectively proportional to 0·013573 and 0·015043. Hence for the weight of steam actually delivered to each end of the cylinder we get

Front end . . . . $M_i = 0·015850$ lb
Back " . . . . $M'_a = 0·017567$ "

In these conditions the weights of steam and water in the cylinder are as follows :—

During expansion, front end . $(M_a + M_c) = 0·017387$ lb.
" " back " . . . . $= 0·019412$ "
During compression, front end . . . . $M_i = 0·001537$ "
" " back " . . . . . . $= 0·001845$ "

For trial III the steam was superheated at the end of admission by heat conducted through the cylinder-wall from the gas-flame jacket. The same procedure has, however, been adopted in the absence of any better.

Having thus divided the steam expended in a revolution between the two single strokes, each single stroke is treated entirely as if made by a separate engine. For each stroke (back and front) the work done and the heat-exchange has been determined, for each period, admission, expansion, exhaust, and compression, also the absolute work and the absolute loss by heat-exchange. Then only the means have been taken of the volumes, the work, and the exchanges, and from these means the diagrams were drawn. It is believed that no other reasonable division of the steam would have led to sensibly different results.

As to the exact curve of heat-exchange during expansion, it differs so much for the two ends of the cylinder that the Author gave up the idea of showing it on the diagrams.

12. *Classification and Tabulation of the results.*—The results are given in the following tables, and are figured on the diagrams :—

Volumes described by the Piston.

During admission . . . . . $V_a = 0·2422$ cubic foot.
" expansion . . . . . $V_d = 0·1318$ "
" exhaust . . . . . . $V_e = 0·4373$ "
" compression . . . . . $V_c = 0·0781$ "
" single stroke . . . . $V_f = 0·4477$ "

DONKIN'S EXPERIMENTS.

—		Condensing.			Non-condensing.	
		I bis. With Gas-flame Jacket, Aug. 9.	I. With Gas-flame Jacket, Aug. 8.	II. No Jacket, Aug. 9.	III. With Gas-flame Jacket. July 31.	IV. No Jacket, July 26.
Heat expended in steam per stroke	Q	19·5095	17·9986	22·6739	23·2164	29·9701
Weight of steam per stroke . .	π	0·016504	0·015212	0·019164	0·019690	0·025330
Work during admission . .	T_a	1·1507	1·0538	1·2105	1·8936	1·8196
Work during pre-admission . .	T''_a	0·0186	0·0139	0·0187	0·0159	0·0414
Work during expansion. . .	T_d	0·4443	0·4026	0·4683	0·7350	0·7143
Work during exhaust . . .	T_e	0·1674	0·1117	0·2236	0·7561	0·6800
Work during pre-exhaust . .	T'_e	0·1635	0·1505	0·1840	0·2720	0·2827
Work during compression . .	T	0·1081	0·0891	0 1413	0·3815	0·3306
Work during total stroke . . .	$T_,$	1·7771	1·6200	1·8806	2·9461	2·8666
Indicated work .	T	1·3195	1·2556	1·3139	1·4910	1·5233
Heat - exchange during admission	$R_,$	2·4294	2·1853	4·6167	−0·2604	4·8812
Heat - exchange during expansion	R_d	−0·4315	−0·3696	−0·9720	−0·7102	−0·4847
Heat - exchange during exhaust	R_e	2·0328	1·9298	3·7512	0	4·4992
Heat - exchange during compression . .	R	0·0844	0·1290	0·1984	0·7006	1·1063
Heat lost by steam to walls $R_, + R_c + R_d =$	$R_,$	2·0823	1·9146	3·8411	−0·3000	4·5184
Thermal units in steam leaving the cylinder .	U_1	17·7380	16·2060	19·5831	27·0776	29·1618
Internal rejected heat	$U_1 - U_2$	15·9404	14·6753	17·2767	21·2693	23·2409
$T' + T''_a + T_c$ . .		0·2902	0·2535	0·3440	0·6994	0·6547

All quantities in thermal units, except π which is in lbs.

The Table below gives the value of the same quantities as the previous Table, expressed as a fraction of the heat Q carried into the cylinder by the steam.

—	Condensing.			Non-condensing.	
	I bis. With Gas-Jacket, Aug. 9.	I. With Gas-Jacket, Aug. 8.	II. No Jacket. Aug. 9.	III. With Gas-Jacket, July 13.	IV. No Jacket, July 26.
T_a	0·0590	0·0585	0·0534	0·0816	0·0607
T''_a	0·0010	0·0008	0·0008	0·0020	0·0014
T_d	0·0228	0·0224	0·0207	0·0317	0·0238
T_e	0·0086	0·0062	0·0099	0·0326	0·0227
T'_c	0·0084	0·0084	0·0081	0·0117	0·0094
T_c	0·0055	0·0050	0·0062	0·0164	0·0110
T_f	0·0911	0·0900	0·0829	0·1269	0·0956
T	0·0676	0·0698	0·0579	0·0642	0·0508
R_i	0·1245	0·1214	0·2036	−0·0112	0·1629
R_d	−0·0222	−0·0205	−0·0429	−0·0319	−0·0162
R_e	0·1042	0·1072	0·1654	0	0·1501
R_c	0·0043	0·0072	0·0088	0·0302	0·0369
R_f . . .	0·1067	0·1080	0·1691	−0·0129	0·1508
U_1	0·9092	0·9003	0·8637	1·1663	0·9730
$U_1 - U_2$	0·8171	0·8153	0·7620	0·9161	0·7755
$T'_e + T'_c + T$.	0·0149	0·0141	0·0152	0·0301	0·0218

The following Table gives the results of the calculations for drawing the diagrams of work pressure and exchange.

—		I bis.	I.	II.	III	IV.
Mean pressure during admission . . .	p_i	222000	221000	201000	307000	229000
Mean pressure during expansion . . .	p_d	158000	155000	143000	219000	165000
Mean pressure during exhaust . .	p_e	18000	13000	21000	68000	47000
Mean pressure during compression . .	p_c	65000	58000	73000	192000	129000
Mean absolute pressure during stroke	p	186000	184000	169000	258000	194000
Mean exchange-pressure during admission	r_i	469000	458000	768000	−42000	614000
Mean exchange-pressure during expansion . . .	r_d	−153000	−142000	−297000	−220000	−343000
Mean exchange-pressure during exhaust	r_e	217000	224000	315000	0	314000
Mean exchange-pressure during compression . . .	r_c	51000	84000	102000	352000	432000
Total mean exchange-pressure during stroke	r_f	218000	220000	346000	−30000	307000

All quantities in lbs. per square foot per lb. of steam. These are the data used in tracing the diagrams given in this Paper.

13. *Remarks on drawing the diagrams.*—Following Professor Unwin, the positive surfaces which represent heat received by the metal are distinguished from the negative surfaces which represent heat restored to the steam by the inclination of the shading.

In the diagrams for trials I *bis*, I, II, and IV, the positive area is greater than the negative area by a quantity which represents the heat which the steam finally lost, and which has been transmitted through the cylinder sides whether there was a gas-flame jacket or not. In trial III, the contrary occurs, and the steam receives more heat from the cylinder sides than it yields to them. The gas-flames in effect drive heat through the metal. This is a capital fact which explains the action of the gas-flame jacket and gives a high value to Mr. Donkin's experiments.

14. *Remarks on the action of the gas-flame jacket.*—Mr. Hirn has already said that the economy due to the steam-jacket, although very considerable, was occasioned by a very small quantity of heat traversing the metal of the cylinder. The trials I *bis* and I show a notable economy, while ultimately no heat due to the gas-flames traversed the metal of the cylinder, since in the end it is found that more heat has been given to the sides by the steam than received by the steam from the metal. The effect of the gas-flames is merely to hinder external radiation.

15. *Economy of the gas-flame jacket.*— The economy of steam due to the use of a gas-flame jacket is undeniable and considerable. The following figures and the diagrams make this clear.

First, as to the consumption of steam per absolute HP. and per indicated HP. per hour, in the five trials of Mr. Donkin. We define the consumption thus: A HP. corresponds to 1,980,000 ft.-lbs. per hour. But in the trial π lbs. of steam were necessary to do 772 $(T'_a + T_d + T'_c) = 772\ T_f$ foot-lbs. of absolute work. Then the steam-consumption per HP. absolute per hour is

$$\pi \frac{1,980,000}{772\ T_f}.$$

Similarly the consumption per indicated HP. per hour is

$$\pi \frac{1,980,000}{772\ T}.$$

—	With Gas-flame Jacket		Without Jacket	With Gas-flame Jacket.	Without Jacket
	I bis.	I	II.	III.	IV.
Effective consumption in lbs . . . . π	0·016503	0·015212	0·019164	0·019690	0·025330
Absolute work in thermal units . . T_f	1·7771	1·6200	1·8806	2·9464	2·8666
Absolute work in foot-lbs . . 772 T_f	1,372	1,251	1,452	2,275	2,213
Consumption of steam per absolute HP per hour in lbs	23·82	23·97	26·14	17·14	22·66
Indicated work in thermal units . . T	1·3195	1·2556	1·3139	1·4910	1·5233
Indicated work in foot-lbs . . 772 T	1,019	969	1,014	1,151	1,176
Consumption of steam per I HP per hour in lbs .	32·08	31·07	37·41	33·87	42·65

The Table shows that in the trials I *bis* and I, compared with II, there is an economy of steam per absolute HP. of 8·9 and 8·3 per cent., and per indicated HP. of 14·2 and 16·9 per cent. In trial III compared with IV, there is an economy of steam per absolute HP. of 24·4 per cent. and per indicated HP. of 20·6 per cent.

16. *Explanation of the economy.*—While the steam is enclosed in the cylinder from the commencement of compression to the beginning of exhaust, it gives heat to the metal, so that ultimately it has lost a quantity which may be called the final loss due to the action of the cylinder-sides, and is denoted by $R_f = R_c + R_a + R_e$. In fact since at the end of a revolution the metal returns to its initial condition, it is necessary that that total quantity of heat should have left the metal. Part is lost internally during exhaust, the internal radiation which Hirn calls cooling due to the condenser, and which for more generality may be termed exhaust-cooling, and which is denoted by R_c. The other part traverses the metal and is lost by external radiation during the whole stroke, and this is denoted by E.

When there is no jacket, the total loss is $R_c + E$. It is also expressed in another manner, as will be shown, so that

This equation will determine the external radiation E, if R_e R_c R_a

are known. What is wanting in Mr. Donkin's trials for a complete determination will be pointed out presently.

If there is a jacket in which a quantity of heat Q' is generated, a part E is radiated externally, and another part Q' − E traverses the cylinder-wall, and is given to the steam. In other words the heat which passes from the exterior of the cylinder-wall is no longer E, but is E − Q'. Hence the internal loss being always R, the external loss (which may be a gain) is E − Q'. Consequently

$$R_e + E - Q' = R_c + R_a + R_d.$$

17. *Resultant action of the sides.*—By the method indicated above R_e has been calculated and from the equations just given E or E − Q' has been calculated according to the case. The results are given below.

Quantities in thermal units except in last line but one	With Gas-flame Jacket		Without Jacket	With Gas flame Jacket	Without Jacket
	I bis	I	II	III	IV.
Final loss of heat by walls $R_c + R_a + R_d$	2·0823	1·9446	3·8411	−0·3000	4·5184
Loss by interior surface of walls . . . . . R_e	2·0328	1·9298	3·7512	0	4·4992
Difference, loss by external surface	E − Q' =0·0495	E − Q' 0·0148	E 0·0899	E − Q' −0·3000	E 0·0192
The same quantity divided by absolute work .	0·028	0·009	0·048	−0·102	0·006
Absolute work	1·7771	1·6200	1·8806	2·9164	2·8666

It will be seen first that E or E − Q' is an important fraction of the absolute work except in the last trial. The difference between trials II and IV may be due to error of observation, especially as R is calculated from a single datum the pressure at the beginning of exhaust shown on the diagram. A small error in determining this would lead to large differences in the value of E.

18. *Deficiency for a complete study.*—In his trials Mr. Donkin has not measured the external radiation E, nor the heat generated in the jacket Q'. Thus data are wanting to determine directly the heat rejected externally from the metal. It is no better as to the heat rejected internally in the non-condensing trials, since its experimental determination is not possible, nor in the condensing trials since the weight and temperature of the condensing water were not observed.

19. ***Means of determining the exhaust cooling when it is not directly***

measured.—The heat absorbed by the metal and rejected to the condenser during exhaust comprises an unavoidable portion, that necessary to vaporize the water on the cylinder-walls at release. At that moment the pressure is suddenly lowered, the saturation temperature is lowered also, and becomes less than that of the metal. The heat of the metal, therefore, is communicated to the water covering it, and evaporates it to the condenser. The vaporization requires an amount of heat proportional to the weight of water evaporated and the internal latent heat ρ per lb. of water corresponding to the pressure.

To calculate that quantity the pressure P_1 at release, and the volume V_1 in the cylinder is measured from the diagram. Steam Tables give the density δ_1 of the steam in lbs. per cubic foot. Hence the weight of steam in the cylinder at release is

If also the total weight of mixed steam and water present $M_a + M_c$ is known, and that weight is greater than m_1, there must be in the cylinder

$$M_a + M_c - m_1 \text{ lbs. of water.}$$

The Tables give for P_1 the internal latent heat ρ_1 per lb., and it may be inferred that

$$(M_a + M_c - m_1)\ \rho_1 \text{ thermal units}$$

is the quantity of heat which the metal furnishes to vaporize the water. If m_1 is greater than $M_a + M_c$ it may be inferred that the steam is superheated. In that case no heat is borrowed from the metal as there is no water to evaporate.

After having compared the results obtained by this calculation with those given by direct experiment the Author is convinced that there is no sensible error in supposing the exhaust cooling R_e to consist only of the heat necessary to vaporize the water present at release. Hence

$$R_e = (M_a + M_c - m_1)\ \rho_1$$

when the steam is supersaturated ; and

when the steam is dry or superheated at release.

20. *Peculiarity of Trial III.*—These formulas have been used to calculate the exhaust-cooling in the trials in question. The equation $R_e = 0$ is only applicable in trial III where the jacket

heat superheated the steam during admission and maintained the superheating during expansion. It is the first trial of the kind the Author has studied. The superheated steam used in Hirn's trials in the engine at Logelbach[1] did not remain superheated during expansion, and was only superheated at the end of the expansion in one trial, that made without condensation. It is again in a trial without condensation that the steam is superheated at the end of the expansion in the case now considered. But there is a remarkable peculiarity, namely, that even during the admission the action of the gas-flame jacket gives heat enough to the steam to superheat it. The cylinder was transformed into a very rapid superheating apparatus, since fresh steam entered one hundred and eighty-six times per minute.

But in the calculations everything depends on the pressure at release, and the least error in this would have large consequences. The Author believes there is an error of this kind in trial IV, and that the internal heat of the steam U_1 as well as the pressure has been taken too great.

21. *Variation of the dryness-fraction during expansion.*—It is useful to take into consideration the variations of dryness during the expansion. The following is a Table of means of the two single strokes of the piston:—

—		I bis. Jacket.	I. Jacket.	II. No Jacket	III. Jacket.	IV. No Jacket
Dryness-fraction at beginning of expansion . . .	x_0	0·870	0·869	0·770	Superh.	0·797
Dryness-fraction at end of expansion	x_1	0·877	0·873	0·805	Superh.	0·834
Increase of dryness-fraction .		0·007	0·004	0·035	..	0·037

With the jacket (I, I *bis*) the heat it furnishes diminishes the condensation, since the dryness-fraction 0·87 is larger than with no jacket (namely 0·77 in II). In trial III the steam has been superheated, while without jacket in IV the dryness-fraction falls to 0·797, or 20 per cent. of the steam is condensed.

On the other hand, the heat restored by the cylinder-sides during expansion is much greater without a jacket than with a jacket. But the final dryness-fraction x_1 is always greater with the jacket acting. These facts are shown clearly by the diagrams of exchanges.

---

[1] See the Author's Memoir. Bulletin de la Société de Mulhouse.

22. *Results shown by the diagrams.*—The area R'_a, which represents the heat given to the metal during admission, is smaller in trials I, I *bis*, with gas-flame jacket than in II without jacket. In trial III, with gas-flame jacket, the metal heats the steam, while in IV, without jacket, the steam gives heat equal to the latent heat of 20 per cent. of its weight.

The area R_d, which represents heat restored by the metal to the steam during expansion is, on the other hand, greater in the two trials without jacket.

The heat R_c, lost by the steam in heating the metal during compression, appears to be greater when the jacket is not acting.

The final result $R_o + R_a + R_d$, which is specially important from the point of view of economy, is represented on the diagrams in a striking way. In all the trials except III the total loss due to the metal is represented by a rectangle of which the height is very nearly equal to that which represents the loss during exhaust R_e. It is obvious that the final loss is smaller in I and I *bis* with jacket than in II and IV without jacket. Also that in II without jacket and condensing the loss is greater than in IV without jacket and non-condensing. In Trial III there is no loss of heat during exhaust but a gain. Heat traverses the metal and is given to the steam during each stroke of the piston. In that case R_e is taken $= 0$. The rectangle of which the height represents the final loss is below the axis, and at a distance somewhat great.

23. *Conclusions.*—The diagrams show very well that the energy of action of the gas-flame jacket is diminished when a condenser is used; that the action occurs especially during admission, diminishing the initial condensation; that the increase of dryness during expansion is less when the jacket acts, and finally the total loss is diminished by the jacket.

The following considerations throw light on the influence of the jacket, and show that progress may yet be made.

24. *Balance-Sheet of the Engine.*—The total heat which does work is, with no jacket, Q thermal units, which the steam carries into the cylinder.[1] But with a jacket there is added Q′ thermal units of heat generated in the jacket. The total heat is then $Q + Q'$. It is then to Q for an engine without jacket, and to $Q + Q'$ for an engine with a jacket, that it is necessary to refer all other quantities of heat.

An exception must be made in the trials of Mr. Donkin, for two reasons. One is that Q' was not measured; the other is that the cost of a thermal unit obtained from gas is different from the cost of a thermal unit obtained in evaporating the steam. Then, whether the jacket acts or not, the other quantities of heat must be referred to Q in order to remove objections.

---

[1] It is supposed that the boiler is fed with water at 32° Fahrenheit, and that the total heat is reckoned from that temperature.

The heat Q carried to the cylinder by the steam is expended for three objects:—

1st. To do the absolute external work T_f, whatever use the manufacturer makes of it; whether, for example, he abandons the advantage of condensation or makes use of it.

2nd. To heat uselessly the metal, which involves a final loss $R_c + R_a + R_d$, occasioned by external radiation E, or by internal radiation R_e.

3rd. The third part is complex, and comprises—the internal heat U_1 which the steam possesses when it leaves the cylinder, diminished by the internal heat U_2 of the steam retained in the cylinder by cushioning. Also the quantities of work T_c during compression, T''_a during pre-admission, and T'_ι during pre-release. It may be separated into two parts, $U_1 - U_2$ and $T'_c + T_c + T''_a$, the last negative and generally small.

The following justifies this division. The total heat expended $Q + Q'$ is equal to that corresponding to the indicated work T, plus the heat rejected by external radiation E, plus the heat rejected by internal radiation which goes into the condenser or the atmosphere, with the notation already explained.

Heat rejected by internal radiation $= U_1 + R_e + T_e - U_2$,

whence

$$Q + Q' = (T'_a + T_d + T'_c) - (T''_e + T_c + T''_a) + U_1 - U_2 + T_\iota + R_\iota + E.$$

But

$$R_e + E - Q' = R_\iota + R_a + R_d = R_f,$$

and

$$T'_a + T_d + T'_\iota = T_f,$$
$$T_e = T''_e - T'_e.$$

Whence

$$Q = T_f + R_f + U_1 - U_2 - (T'_e + T_\iota + T''_a).$$

Giving, then, separately the values of the four terms in the following formula—

$$1 = \frac{T_f}{Q} + \frac{R_f}{Q} + \frac{U_1 - U_2}{Q} - \frac{T'_e + T_\iota + T''_a}{Q},$$

which form the balance sheet of the engine.

25. *Supplementary Explanation.*—Let τ be the temperature (abso-

lute) of the boiler-steam, and τ' that of the condensing-water, or of the atmosphere. The fall of temperature is $\tau - \tau'$. The maximum work which can be obtained is $\frac{\tau - \tau'}{\tau}$ of the heat expended, and the minimum which must be abandoned to the cold body, that is, the unavoidable loss of heat, since the steam cannot be reduced below the temperature of the condensing-water or atmosphere, is $\frac{\tau'}{\tau}$. The value of $\frac{\tau'}{\tau}$ is about 0·7, and that of $\frac{\tau - \tau'}{\tau}$ is about 0·3. Since the absolute work scarcely exceeds 10 per cent. of the heat expended, while a perfect motor would utilize 30 per cent. for the same range of temperature, it is obvious that the engine had a relative efficiency of about 33 per cent.

26. *Means of Increasing the Efficiency.*—The question arises naturally, Are there no means of increasing the efficiency of the steam-engine? Three means are principally employed.

1st. To give heat to the steam in the cylinder while doing work. To this end a steam jacket is used with success; a hot-air jacket without success. Lastly, Mr. Donkin heats the outside of the cylinder by means of gas flames. He puts the cylinder, as it were, in a gas furnace. The trials show the efficiency of this method.

2nd. Superheating the steam before its introduction into the cylinder. It was the method used by Hirn, thirty years ago, in the engine at Logelbach, and the success of which is not doubtful. For practical reasons it has been abandoned for some time, but, with a view to economy, it would be well to return to it.

3rd. The perfect experiments of Mr. Willans (1886) have removed all doubt as to the economy which may be obtained by great piston-speed.

The Author desires to give an account of the natural processes through which the gas-flame jacket of Donkin, the superheating of Hirn, and the high speed of Willans give rise to a considerable economy. Thanks are due to these engineers for details of their trials, so complete that it has been possible to make a study of them by the Author's method. The comparison of the results of the three methods is useful, because it leads to a general conclusion. The flame-jacket, superheating, high speed, all have the same complex effect, which is this:—

To augment the absolute work.

To diminish the final loss due to the metal.

To increase the other losses by an amount less than the gain in diminishing the influence of the cylinder sides.

That it is so cannot be shown better than by giving the Table of the results obtained by these three methods. Those relating to the trials of Hirn, in 1873 and 1875, are the translation into English measures of the figures given in the Author's memoir in the "Bulletin de la Société Industrielle de Mulhouse."

27. *Utility of the gas-flame jacket of Donkin.*—From a comparison of the results of the trials, it is found that with the gas-flame jacket—

With condensation:—

The absolute work is increased by	0·008
The loss due to the cylinder-sides is diminished by	0·063
The other losses are increased by	0·055

Without condensation:—

The absolute work is increased by	0·031
The loss due to the cylinder sides is diminished by	0·164
The other losses are increased by	0·133

The other losses comprise, as a principal term, the internal heat U_1 of the steam leaving the cylinder. The effect of the jacket is to increase this so that the absolute work does not gain by all the diminution of the loss due to the action of the cylinder sides. This is natural, because the steam is raised to a higher temperature and greater dryness at release. The economy due to the jacket seems limited by this fact.

It seems that the maximum effect of the jacket should be obtained when the heat traversing the cylinder-sides renders the steam dry at the end of the expansion, or even superheats it. That happened in a trial of Donkin's, without condensation with jacket, and in a trial of Hirn's without condensation and with superheating. The Author has concluded that in that case the internal radiation is nearly suppressed. Water, that powerful vehicle of heat, as Hallauer terms it, is absent.

The economy of steam with the Donkin jacket is demonstrated. But what expenditure of heat must be made in the jacket to procure the benefit? No reply can be given at present, as the heat developed in the jacket was not measured, or that lost by radiation, although the gas used was measured by meter. Only one remark may be made. The quantity of heat which gets through the cylinder in all is small. With condensation the work is increased only by 0·008, and without condensation only by 0·031. Only these $\frac{8}{1,000}$ represent 10 per cent. of the work obtained without the jacket, and these $\frac{31}{1,000}$ represent 33 per cent.

of the work obtained without the jacket. Is not there the explanation of the fact?

28. *Utility of superheating.*—The trials of Hirn (1873) numbered I and II, and the trials (1875) numbered V and VI, were made to determine the utility of superheating. In the two trials of each series there was the same ratio of expansion, nearly the same boiler-pressure, and the same speed. The only difference was that in trials I and V the steam was superheated to 448° and 384° respectively, while in the two others the steam was saturated, or a little wet. There was a condenser in both cases, but in 1873 the condenser did not give a good vacuum. The effect of superheating was—

Trials I and II (1873):—

The absolute work was augmented by . . $0·143 - 0·117 = 0·026$
The loss by cylinder-sides was diminished by $0·147 - 0·067 = 0·080$
The other losses increased by . . . . . $0·790 - 0·736 = 0·054$

Trials V and VI (1875):—

The absolute work was increased by . . . $0·146 - 0·124 = 0·022$
The loss by cylinder-sides was diminished by $0·250 - 0·150 = 0·100$
The other losses increased by . . . . . $0·704 - 0·626 = 0·078$

The resultant benefit reckoned on the absolute work is 22 per cent. in the first case and 18 per cent. in the second. The superheating, like the jacket, increases the absolute work, and diminishes still more the loss due to the cylinder-sides. But the absolute work does not profit by all the difference, because the steam is hotter and drier at the end of the expansion.

29. *Utility of high speed.*—The diagrams, Plate 2, are arranged in the order in which Mr. Willans arranged his trials. The Table below is classed according to speed. The four groups of diagrams have a common character, specially well marked in the group IV, V, VI, the trials being made at 409·1, 205·2, and 112·7 revolutions per minute. Let the trials be compared in the following order: IV with V, V with VI, IV with VI. At the higher speed—

Trials IV and V, at 409 and 205 revolutions:—

The absolute work was increased by . . . $0·105 - 0·095 = 0·010$
The loss due to the sides was diminished by . $0·160 - 0·130 = 0·030$
The other losses increased by . . . . . $0·765 - 0·745 = 0·020$

Trials V and VI, at 205 and 112 revolutions:—

The absolute work was increased by . . . $0·095 - 0·079 = 0·016$
The loss due to the sides was diminished by . $0·258 - 0·160 = 0·098$
The other losses increased by . . . . . $0·745 - 0·663 = 0·082$

Trials IV and VI, at 409 and 112 revolutions :—

The absolute work was increased by . . .	0·105 − 0·079 = 0·026
The loss due to the sides was diminished by .	0·258 − 0·130 = 0·128
The other losses increased by	0·765 − 0·663 = 0·102

The resultant benefit reckoned on the absolute work was—

Trials IV and V	10·5 per cent.
„ V and VI	20·2 „
„ IV and VI	32·9 „

The analogy of the conclusions is striking.

30. *Comparison of the three methods.*—In order to draw from the experiments discussed some conclusions as to the comparative merit of the three methods, it is convenient to find the consumption of steam per absolute HP. per hour. The quantity of steam per indicated HP. may also be given; but then condensing and non-condensing engines are no longer comparable.

Even for the absolute work some difficulties arise, for the ratio of expansion was not the same in different trials. The Table below gives the results of twenty-five trials, with very different ratios of expansion, and so much more so since the clearance was 10 per cent. in the trials of Donkin, 1 per cent. in the trials of Hirn, and 7 per cent. in those of Willans. The ratio of the volume at cut-off to that at release is indicated in the Table. For the trials with gas-flame jacket it is constant, and equal to 0·684. For those on superheated steam it varied from 0·162 to 0·454; for the trials at different speeds, from 0·280 to 0·497.

In Donkin's trials the minimum consumption of steam, without regard to the heat supplied by the jacket, was 17·14 lbs. per absolute HP. per hour, with cut-off at 0·684. In the trials of Hirn, 16·02 lbs. per absolute HP. per hour, with cut-off at 0·454. In the trials of Willans, 21·80 lbs. per absolute HP. per hour, with cut-off at 0·497.

The minimum consumption of the Willans engine was 17·90 lbs., with cut-off at 0·280. With a cut-off at 0·287, and without condensation, the consumption of Hirn's engine was 15·19. With cut-off at 0·162 and condensation, it fell to 14·59.

It is strange that the consumption in lbs. per absolute HP. per hour in trial IV of Donkin, without gas-flame jacket, should be smaller than in trial I with condensation and gas-flame jacket. But the steam-pressure during admission was greater in trial IV than in trials I and I *bis.*

1888.—DONKIN'S GAS-FLAME-JACKET TRIALS.

Double-acting; nearly full steam; piston-speed about 210 feet per minute.

—	Gas-Flame Jacket.			No Jacket.	
	Condensing.		Non-Condensing	Condensing.	Non-Condensing.
Date of trial . . .	Aug. 9	Aug. 8	July 31	Aug. 9	July 26
No. in this Memoir .	I *bis*	I	III	II	IV
Donkin's experimental No. . .	No. 3	No. 2	No. 9	No. 4	No. 3
Clearance	0·102 of volume generated per stroke.				
Real degree of expansion	0·684	0·684	0·684	0·684	0·684
Boiler-pressure, lbs. absolute . . .	49·70	49·20	50·20	49·20	50·20
Temperature of superheating	..	..	..	..	..
Higher temperature .	741°	739°	Steam superheated all stroke.	740°	742°
Lower ,,	520°	520°		520°	520°
Maximum work . .	0·298	0·296		0·297	0·299
Minimum loss . .	0·702	0·704		0·703	0·701
	1·000	1·000		1·000	1·000
Absolute work . .	0·091	0·090	0·127	0·083	0·096
Loss by walls . .	0·107	0·108	0·013	0·170	0·151
Other losses . . .	0·802	0·802	0·886	0·747	0·753
Loss by internal heat of exhaust-steam .	0·817	0·815	0·935	0·762	0·775
Calculated efficiency	0·305	0·304	..	0·279	0·321
Lbs. of steam per absolute HP. hour .	23·82	23·97	17·14	26·14	22·74
Indicated HP. . .	6·05	5·47	6·33	5·61	6·26
Absolute HP. . .	8·15	7·09	12·51	8·03	11·74
Lbs. of steam per indicated HP. hour	32·08	31·07	33·87	37·41	42·65

1873 and 1875.—HIRN'S SUPERHEATING TRIALS; NO STEAM-JACKET.

Double-acting; piston-speed about 335 feet per minute; 30 revolutions per minute.

Superheated Steam.						Saturated Steam.	
Condensing.					Non-Condensing.	Condensing.	
Sept. 7 V	Aug. 26 III	Nov. 18, 1873 I	Aug 27 IV	Sept. 29 VII	Oct 28 VIII	Sept. 8 VI	Nov 28, 1873 II
		0·010 of volume generated per stroke.					
0·162	0·214	0·257	0·454	0·454	0·287	0·162	0·257
70·66	71·03	69·55	69·34	71·48	62·23	70·70	66·14
384°	419°	448°	433°	428°	428°	..	..
843°	878°	907°	893°	897°	897°	763°	758°
521°	521°	514°	521°	519°	515°	521°	512°
0·382	0·407	0·433	0·416	0·414	0·420	0·317	0·324
0·618	0·593	0·567	0·584	0·586	0·580	0·683	0·676
0·146	0·144	0·143	0·124	0·126	0·141	0·124	0·117
0·150	0·114	0·067	0·119	0·138	0·004	0·250	0·147
0·704	0·743	0·790	0·757	0·736	0·863	0·626	0·736
0·705	0·743	0·790	0·759	0·737	0·871	0·627	0·736
0·382	0·354	0·330	0·298	0·304	0·336	0·391	0·361
14·59	14·96	14·94	17·25	16·02	15·19	17·18	18·27
113·08	135·77	144·36	125·17	99·53	78·30	107·31	136·46
125·20	148·18	168·36	137·60	111·01	146·88	121·75	160·64
16·16	16·26	17·43	18·96	19·25	28·49	19·41	21·51

1886.—NON-CONDENSING; WILLANS'S

Single-acting; expansion varies

—	High Speed [400 Revs.]. Piston Speed, 400 feet per minute.			
	400·16	400·9	409·1	408·4
Date of trial	Dec. 5	Nov. 30	Dec 8	Dec. 6
No. in this Memoir	X	VII	IV	I
Clearance			0·070 of volume	
Real degree of expansion	0·280	0·327	0·401	0·497
Boiler-pressure, lbs. absolute	136·74	111·75	88·57	65·46
Temperature of superheating				
Higher temperature	810°	795°	778°	758°
Lower "	519°	517°	524°	524°
Maximum work	0·359	0·349	0·326	0·308
Minimum loss	0·641	0·651	0·674	0·692
Absolute work	0·120	0·116	0·105	0·100
Loss by walls	0·126	0·106	0·130	0·147
Other losses	0·754	0·778	0·765	0·753
Loss by internal heat of exhaust-steam	0·762	0·784	0 771	0·759
Calculated efficiency	0·334	0·332	0·322	0·320
Lbs of steam per absolute HP. hour	17·90	18·40	20·30	21·80
Indicated HP	35·33	32·85	27·44	19·67
Absolute HP	49·33	46·52	41·00	33·16
Lbs. of steam per indicated HP. hour	24·75	25·88	30·28	36 15

SPEED-TRIALS; no STEAM-JACKETS.

from a quarter to a half.

Mean Speed [210 Revs.]. Piston Speed, 210 feet per minute.				Low Speed [115 Revs.]. Piston Speed, 115 feet per minute.			
223·7	223·0	205·2	200·6	138·0	122·8	112·7	110·5
Dec. 2	Nov. 30	Dec. 9	Dec. 7	Dec. 5	Dec. 1	Dec. 8	Dec. 6
XI	VIII	V	II	XII	IX	VI	III
generated per stroke.							
0·280	0·327	0·401	0·497	0·280	0·327	0·401	0·497
126·98	99·40	80·97	58·57	120·14	94·93	76·40	54·69
804°	786°	772°	751°	800°	783°	768°	746°
519°	519°	525°	519°	519°	525°	527°	509°
0·355	0·340	0·320	0·308	0·351	0·329	0·313	0·317
0·645	0·660	0·680	0·692	0·649	0·671	0·687	0·683
0·097	0·116	0·095	0·092	0·093	0·091	0·079	0·079
0·189	0·116	0·160	0·133	0·214	0·205	0·258	0·230
0·714	0·768	0·745	0·775	0·693	0·704	0·663	0·691
0·719	0·774	0·751	0·781	0·697	0·708	0·669	0·696
0·273	0·341	0·297	0·299	0·265	0·277	0·252	0·244
22·00	18·40	22·50	23·30	22·90	23·60	27·20	27·80
20·58	17·86	14·66	10·04	13·36	10·32	8·07	5·64
28·27	25·28	21·39	16·56	17·97	14·43	11·85	9·20
30·06	26·05	32·98	38·79	30·06	32·93	40·04	44·65

(*Paper No. 2374.*)

"The Improvement of the River Avon below Bristol."

By WILLIAM CHATHAM, Assoc. M. Inst. C.E.

THE River Avon forms the channel, about 7 miles in length from the anchorage at Kingroad, by which access is obtained to the Port of Bristol, which, at one time, was second only to London, though now it ranks eighth among the ports of the kingdom. This decline has been in a great measure due to the tortuous course of the river, the improvement of which has not kept pace with the ever-increasing demands of the mercantile marine.

A short distance below the city, the river enters the narrow and precipitous gorge bounding the Clifton and Durdham Downs, and it is here that the principal obstacles to navigation have existed, in consequence of the projection of five "elbows" of rock into the channel, called Hotwell House Point, Suspension Bridge Point, Round Point, Tea-and-Coffee House Point, and Pheasant Quarry Point, respectively (Plate 3, Fig. 1). The first and third of these points are on the Gloucestershire side and the others on the Somersetshire side of the river. They are chiefly composed of mountain limestone, and have been found to consist of very hard and jointy beds of rock, difficult to bore. The dip of the strata is to the south-east or up-stream at an angle of about 30°. Just above Round Point, the Clifton fault occurs which throws the strata down to the south a depth of over 1,100 feet, producing great distortion at the point referred to, where the rock is composed principally of millstone grit, or, as it is locally termed, "Fire-stone." Once clear of these obstacles, the course is continued by tolerably straight reaches for about 2 miles, and then a bend occurs, called Horse Shoe Point. Although by far the greatest bend in the navigable portion of the river, it is less dangerous than the "elbows" of rock just described, because the channel is wider and deeper, and the point consists of level ground, permitting a clear view up and down stream. Immediately after rounding Horse Shoe Point, the river tends to resume its direction towards the Severn, and here its scouring effect becomes greater than at any other part of its course, resulting in the production of a stretch of deep water known as Hungroad, which is sometimes used as a mooring-ground by vessels arriving after high-water of neap-tides. It was so used by the "Great Western," the pioneer of ocean steam traffic, whose moorings still exist to mark the spot. Below Hungroad the river flows in a comparatively straight line past Avonmouth Dock, and finally sweeps round to join the deep-water channel of the Severn.

Up to 1809, so far as known, the river remained much in its natural state; and the vessels which frequented the port lay aground during low-water, generally in branch docks, which had been constructed for the purpose of shielding them from the currents produced by the flowing and ebbing of the tide. These docks—"mud docks" as they were usually called, a name which clings to them, even yet—were constructed in the heart of the city, and are now used as berths for the smaller class of vessels. The principal branch dock is specially worthy of mention, seeing that its construction dates back to the thirteenth century, and it must be regarded as a large undertaking at so early a period. It consisted of the excavation of a trench through a meadow and marsh, 2,400 feet long, 120 feet wide, and 18 feet deep, and was completed in the year 1247, about eight years having been occupied in its formation.

In 1809, however, a floating-dock, designed by the late Mr. William Jessop and having an area of 63 acres, was formed by impounding the waters of the river where it flows through the city, a new and improved course being provided by the excavation of a channel over 2 miles in length. A tidal basin was constructed; a dam was thrown across the river at Netham, 3¼ miles above the entrance basin; and a feeder-canal was carried from the dam to join the upper end of the dock.

These works were carried out by a private company, in whose hands the dock remained until 1848, when it was taken over by the Corporation, by whom a new and enlarged entrance lock was constructed, after the designs of the late Mr. I. K. Brunel. This lock, which still exists, is barrel-shaped in section, and contains the earliest example of lock-gates made in the form of caissons. Although the necessity of river-improvement had become urgent owing to the increase in the size of vessels, the question was allowed to stand over for a period.

The natural features to be taken into consideration in designing a scheme of improvements were as follow:—

1. The rocky nature of the bed and banks, the difficulties of excavating which increase in proportion with the depth.

2. The very muddy nature of the tidal water, which tends to silt up rapidly any excessive enlargement which may be made in the sectional area of the river.

3. The small volume of tidal back-water and especially the limited average volume of fresh water coming down from the country to scour out and keep open the low-water channel, on which in this case, the very existence of the river as a navigable channel depends.

The second of these features has received a forcible illustration within recent years, by the silting up of the North Channel at the mouth of the river. The calculated quantity of the deposit within ten years (1865–75), over an area of about 50 acres, exceeded 1,000,000 cubic yards.

With regard to the third feature, the flow of the tide is practically limited by Netham dam, only spring-tides rising over its summit, and the channel is narrow throughout the whole distance. The ordinary flow of fresh water in the river is very slight, and, during the summer months, the depth in the channel at various parts does not exceed 1 foot.

It was not until 1864 that a general scheme was adopted and proceeded with, on the recommendation of the late dock engineer, Mr. Thomas Howard; the only work previous to this being the removal of about 70,000 cubic yards of rock and mud from Round Point and Tea-and-Coffee House Point, during the years 1852–55. Whilst the new scheme was under consideration, a contract was let for the removal of a large mass of rock from Tea-and-Coffee House Point. The quantity removed was over 140,000 cubic yards, most of which lay above the level of high-water. Owing to the presence of thin bands of clay between the beds of rock, several slips occurred when the beds were undercut, causing a considerably larger quantity to be excavated than was intended.

Meanwhile, a private company had been formed for the purpose of providing dock accommodation at the mouth of the river for large ocean-going steamers, and, in 1864, it succeeded in obtaining an Act for the construction of a dock.[1] Consequently, in preparing the scheme of river improvements, it was considered unnecessary to provide for the largest class of steamers, as these would no longer care to risk the passage up the river; but, at the same time, it became evident that the new dock would prove a formidable rival for the ordinary class of vessels using the old city dock. Application was therefore made in 1864 for Parliamentary powers for river improvements and collateral works, for which an Act was obtained in the following year.

---

[1] Minutes of Proceedings Inst. C E., vol. lv. p. 3.

The collateral works consisted of a new and enlarged entrance lock to the tidal basin, and a junction lock between the tidal basin and the floating harbour, both of which have been constructed, each being 350 feet long by 62 feet wide at the coping. The sill of the new entrance dock was laid 3 feet deeper than that of the old, giving a depth of water of 33 feet at spring-tides and of 22 feet at neap-tides.

The scheme of river improvements finally decided upon was as follows:—Starting from the entrance lock with a depth of 2 feet below the sill, the deepening of the bed of the river was to be continued at a uniform rate of fall of about 1 in 2,200, an inclination suitable to many parts of the natural channel, and which there was little doubt could be maintained when completed. The width of the bottom of the channel was fixed at 50 feet near the entrance lock, increasing at the rate of about 1 in 1,000, so that it would gradually attain the existing width of the lower reaches of the river, where little alteration would be required; and the banks, where practicable, were to be formed to slopes of 1 in 4, which is about the natural slope of the mud in the upper parts of the river (Plate 3, Figs. 3–7). From the entrance lock for a distance of about 1½ mile down-stream, the line of the channel was laid off with a series of centre curves, varying in radius from 1,500 to 2,500 feet, and joined by short straight lengths, cutting off portions of the five points previously enumerated (Plate 3, Fig. 1). When it is stated that the deep-water portion of the old channel consisted of irregular curves of not more than 600 feet radius, the importance of the improvements will be readily understood. The improvements of the lower part of the river were meanwhile postponed, as they were not considered so urgent as those of the upper part. To provide a new cut for the river at Horse Shoe Point, it has been estimated that 750,000 cubic yards of material would have to be excavated, of which a considerable quantity is rock.

When the contract for the construction of the new entrance and junction locks was let, in the beginning of 1867, the removal of the rock at Hotwell House and Round Points down to 2 feet above low-water level was included under it, and most of the stone used was obtained from this source. The quantities excavated were 37,000 cubic yards of rock, and 1,000 cubic yards of mud and soil, from Hotwell House Point, and 61,000 cubic yards of rock, and 63,000 cubic yards of mud and soil, from Round Point.

At the same time, the excavation of the rock at Suspension

Bridge Point was begun, and as special care had to be observed in connection with the work at this point, owing to the supposed risk of injury to the buttress of the bridge, which was built upon it, this section was carried out by men working under the charge of the dock engineer. The work extended over a number of years, and the quantity excavated above low-water was 49,500 cubic yards.

Hitherto the whole of the work had been confined to the portions of rock lying above the level of low-water, the main object being to open out the view up and down stream. A few years later (1872) a start was made to remove the rock below the level of low-water at Suspension Bridge Point, and, in consequence of the special character of the work, it was considered unadvisable to let it to a contractor. In carrying out the work it was absolutely necessary that the method adopted should not interfere with the navigable channel, which, at the time of high-water, had to be left clear for the passage of vessels. As the best means of doing this, it was determined to form a low-water dam in the bed of the river, so as to enclose the area of rock to be removed, the water being pumped out after the tide had ebbed below the level of the dam. The blasting and removal of the rock could then be carried on during the time of low-water until the tide flowed again. This method has been adhered to throughout the whole of the work, and has enabled it to be carried out with great accuracy and certainty, as it precluded the possibility of any portion of rock being left in the bed of the new channel.

The level of the top of the dam was fixed at about 1 foot above the level of ordinary low-water, or 4 feet above the level of the sill of the new lock, the bottom of the new channel being about 3 feet below the level of the sill at the point in question. At first, old sugar-baskets and sacks, filled with stiff mud or clay, and bundles of faggots weighted with stone, gravel, and mud, were employed in the formation of the dam, but afterwards the top ridding overlying the rock was found to answer the purpose admirably. For filling the hole, a trough or by-wash was formed in the top of the dam, and fitted with a sluice-board, which was withdrawn when the tide began to flow.

The pumping out of the water at Suspension Bridge Point was first attempted by means of hand-pumps and baling with buckets, but these appliances soon proved insufficient. Recourse was next had to screw-pumps, and with the aid of two of these the work was carried on during the next five years. Although these pumps rendered good service, they were very unwieldy for moving from place to place, and the wear and tear were very great. At length, in 1877, an 8-inch Appold's centrifugal pump was obtained, and this class of pump was exclusively adopted at a later period. It was placed in an iron barge, which also carried a 2-ton steam-crane, and a boiler for the supply of steam to the pump-cylinders.

The excavation of the rock was completed in 1880, the quantity removed from the area enclosed by the dam being 5,214 cubic yards. The causes of the work extending over eight years may be summarized as follow. First, the power of the pumps was so small, that although the space for the men to work in was contracted as much as possible, a considerable portion of the time available for working was lost in pumping. Secondly, drilling was almost exclusively done by hand, the rate being about 1 foot to 2 feet per hour. Thirdly, the stone was stored on the river bank at the outset of the work, until there was a barge-load, and it had then to be washed and loaded by hand into the barge, a great deal of time being necessarily spent in breaking it up into small pieces. Fourthly, gunpowder was the only explosive used during the first five years the work was in progress. Fifthly, the only light available to work by at night was that afforded by oil-lamps, known as "ducks."

Two other disadvantages had to be contended with, but these applied equally to all subsequent work. One was the necessity of using light charges in blasting, owing to the proximity of the public roads and dwelling-houses; the other was the tidal deposit of mud, which became very considerable when the work was stopped for a time by freshes in the river, and was occasionally still further augmented by slips from the surrounding banks.

The experience gained in connection with the work at Suspension Bridge Point was sufficient to show that much more powerful plant must be obtained, in order to carry out expeditiously the extensive excavations remaining to be done at Round Point and Tea-and-Coffee House Point, the latter of which contained by far the larger quantity of rock. Accordingly, when it was proposed to commence operations at Round Point, in 1883, an engine-house containing air-compressing and electric-lighting plant was erected on the site of the Tea-and-Coffee House Point, for which it was intended afterwards to be brought into use. The iron barge, with the centrifugal pump and steam-crane, was once more employed, and, a few months later, another iron barge was fitted with a 14-inch centrifugal pump, a 4-ton steam-crane, and a boiler for supplying steam to the pumping-engine. Davits for the electric lamps were fitted up at the ends of the latter barge, the cable from the engine-house being carried along the bank of the river, and provision made for disconnecting it when the barge was afloat. Four rock-drills were also obtained, one Schram and three Eclipse, power being supplied by the air-compressing plant.

On commencing the excavation of the rock, the accumulation of mud overlying it was removed, the dam formed, and a level surface prepared for the barges to ground on. One crane-barge was set to work at each end of the point. As the tide ebbed, each crane-barge was carefully grounded beside the work at right angles to the stream, with an ordinary barge alongside for the reception of the stone. Whenever the level of the water cleared the top of the dam, the sluice-board was inserted in the trough or by-wash, and pumping was begun, the pump having been previously prepared for work, an operation which required only three or four minutes. The time occupied in pumping out the water was, under favourable circumstances, about twenty minutes with the larger pump and thirty-five minutes with the smaller. Drilling and blasting were then actively carried on until the flowing tide put a stop to the operations. As the work proceeded, low cross-walls, loosely built with the smaller pieces of stone, were carried across the hole, and the mud was allowed to silt up behind them, so that the amount of pumping might be kept within reasonable limits. The width of the hole, from the face of the rock to the cross-wall, was about 8 feet, in order to allow the men to work round the skips, and the quantity of water usually amounted to about 50,000 gallons. The average depth of the new channel below the top of the dam at this point was 7 feet 3 inches, and of rock excavated, 3 feet 1 inch. The holes in the rock were almost invariably drilled by machines worked by compressed air or steam, and their direction was generally normal to the bed of the rock. Wherever practicable, gunpowder was used for blasting, dynamite being employed in the case of wet holes only. Twenty-one men were employed in connection with each crane-barge.

With the improved appliances now available, the work at Round Point progressed rapidly, being completed in two years (1883-85). During that period work was carried on by both barges for two hundred and ninety-nine tides, and by one barge only for four hundred and thirty-five tides, of which one hundred and nineteen were occupied in removing mud and débris only. The remainder of the time, amounting to nearly one-third, was lost through freshes in the river, the chief break occurring between December and April each year. The average time between the ebbing and flowing of the tide to the level of the dam was three and a quarter hours, and the time during which the work of drilling and blasting was carried on averaged, as nearly as possible, two and a half hours, the remaining forty-five minutes being occupied in pumping and baling out the water. The total quantity of rock excavated was 4,996 cubic yards (8,730 tons), at a total cost of £4,623, or 18*s.* 6*d.* per cubic yard (10*s.* 7*d.* per ton), details of which are given in the Appendix. The weight of the rock is taken at 145 lbs. per cubic foot. The presence of beds of millstone grit, and the great distortion produced in the strata by the Clifton fault, rendered the rock very difficult to blast.

The greatly accelerated progress made at Round Point as contrasted with Suspension Bridge Point, was due to the following causes:—Owing to the increased pumping-power available ample space was given for the men to work in; drilling was almost exclusively done by machine-drills, the rate being usually about 12 to 13 feet per hour; the stone was loaded direct into barges; dynamite was always available in the case of wet holes; and one of the sections was illuminated at night by electric light.

In giving a description of the crane-barges, reference will be made to one which was obtained about the end of 1886 for the excavations at Tea-and-Coffee House Point, the others being similar, but less powerful (Plate 4, Figs. 8–10). This barge is fully equipped, so that all the operations in connection with the excavation of the rock can be carried on by it, independently of the machinery in the engine-house. It is built of steel throughout, the dimensions being—length, 75 feet; breadth, 21 feet 6 inches; and depth, 6 feet 6 inches. Five elm keels are carried from end to end along the bottom of the barge, and an elm fender is provided along each side, the fenders being further protected by convex steel bars. The barge is divided transversely by four water-tight bulk-heads, one bulk-head near each end, and the other two near the centre; the middle compartment thus formed is further divided by two longitudinal bulk-heads carried up from the keelsons. The end compartments, which are decked over, serve as a cabin for the men and a lock-up for tools, and the main central one as a water-tank for supplying the boiler. The other two main divisions of the barge are left open, and are occupied by the boiler, pump, pipes, rock-drills, &c. The inside of the barge is lined with creosoted yellow pine, 2¼ inches thick.

Above the water-tank is a steam-crane, capable of raising a load of 5 tons at a radius of 21 feet. The crane is worked by a pair of horizontal cylinders, 8 inches in diameter by 12 inches stroke, which are disposed so as to form part of the balance-weight. The jib can be swung through a complete circle and is constructed with plate sides, braced together by lattice-work, so that the man in charge may have a clear view of the load. The main framework of the crane is carried on four steel conical rollers running on a kerb ring of cast-steel, which is left free to revolve on the foundation plate, the inner face being made to gear with the jibbing pinion. The whole of the main gearing is of cast-steel, and the teeth are machine-cut.

Close to the centre compartment and standing across the barge is an 18-inch centrifugal pump driven by a single cylinder, 15 inches in diameter by 12 inches stroke. The suction- and discharge-pipes from the pump are taken through the sides of the barge at the same level, the discharge-pipe being curved down to the sluice-valve, close to the outlet. All the flanges of the pipes are faced; and the joints are made with a single layer of tarred felt, except those next the pump, which are made with india-rubber washers, $\frac{3}{8}$ inch thick. The pipes, where they pass through the sides of the barge, are enlarged and turned, and the joint is made by inserting Tuck's patent packing, $\frac{1}{2}$ inch in diameter, between the plating and a loose collar bolted to it, the latter being slightly checked to hold the packing. The suction-pipes leading from the side of the barge to the bottom of the hole, in order to be thoroughly adapted for the work. required to be capable of being easily connected or disconnected, and to be somewhat flexible so that they might be placed to the best advantage at the deepest part of the hole. Both of these requirements are met by a series of bends with turned and bored spigot-and-socket joints, fitting each other accurately (Plate 4, Fig. 13.)

These bends, three in number, are held together, when the pump is at work, by two bolts, $1\frac{3}{4}$ inch in diameter, which pass through the centre of the pipes and bear upon shoulders cast on the bends. The crossing of the bolts is provided for by an eye formed in one of them, and the nuts are made with short handles so that they may be partially screwed up without the use of a spanner. The bend which projects through the side of the barge is permanently attached to the pump, and the other two bends, which are held together by one of the $1\frac{3}{4}$-inch bolts, form part of the length of movable piping. This piping is kept aboard the barge, bolted together and with chain slings attached, and, when required for pumping, is lifted by the crane and hoisted over the side of the barge, the spigot and socket of the joint to be made having been previously smeared with tallow. The piping is held by the crane in a horizontal position, so that the spigot and socket may be placed together and the bolt inserted. The joint is then securely made by screwing up the bolt, and the suction end is lowered to the bottom of the hole, the swivelling joints formed by the spigots and sockets affording a considerable range to the positions which it may occupy. Immediately the water has been pumped out of the hole, the pipes are again brought to a horizontal position by the crane, the bolt is removed, and they are once more safely stowed aboard the barge. The process of connecting or disconnecting these pipes is extremely simple, and either operation can be performed in two or three minutes. The suction end of the pipes is formed into a fan-tail, protected by a strong wrought-iron grating, the top of the fan-tail overhanging, so that the water may be pumped out to as low a level as possible, without the necessity of providing a deep sump (Plate 4, Fig. 11).

In one of the wings or small compartments alongside the water-tank is placed the dynamo, a series-wound brush-machine, which is driven by one of Heenan and Froude's Tower spherical engines, and gives a current of 20 amperes. The sphere is 6 inches in diameter, and the engine gives 4·32 effective HP. when running at 900 revolutions per minute with a steam pressure of 60 lbs. per square inch. The cable is carried in grooved fillets of wood along the sides of the barge to two 4,000 candle-power Brush arc lamps, one at each end. The lamps hang from short arms at the top of light spars, about 20 feet high, which are placed in sockets in the deck of the barge. Alternative sockets are provided for the spars, one on each side of the centre-line, so that the light can be thrown on either side of the barge.

For the supply of steam to the engines, a 25-HP. Robey semi-portable boiler, which had been used elsewhere, was placed in the main after division of the barge, which it occupies almost entirely.

The total cost of the barge, with all its machinery and equipments, was £2,625.

Shortly after the completion of the work at Round Point in 1885, the extensive excavations at Tea-and-Coffee House Point were taken in hand, and for a time two crane-barges and a salvage tug, which is also specially adapted for the operations, were engaged upon the work there, the number of men employed being about seventy. The total quantity of rock to be excavated below the level of the dam was 15,636 cubic yards, the whole of which was completed in the beginning of April, 1889, and in addition there were 57,470 cubic yards above that level, of which a large proportion has been removed.

At Pheasant Quarry Point, the work of forming a new channel consists chiefly of dredging, and the only portion of rock to be removed lies well above the level of low-water. At Hotwell House Point, where the rock above the level of low-water has been excavated, there is practically none projecting into the new channel below that level, and it may therefore be said that, with the completion of the work at Tea-and-Coffee House Point, the last of a series of formidable obstacles to the navigation of the river will cease to exist. The full benefit of the improvements will not be obtained until some dredging and training-work have been carried out; but already their effect is observable in the decrease of accidents to shipping, though the size and number of vessels coming up to the old City Dock is annually increasing.

In conclusion, it may be mentioned that after the completion of Avonmouth Dock and another Dock at Portishead, which was constructed about the same time, a ruinous competition set in between them and the old City Dock, ending in the transfer of both the new docks to the Corporation of Bristol in 1884. Notwithstanding this, the river improvements have been vigorously carried on, and a large amount of capital is at present being spent upon warehouses and internal improvements at the City Dock. With the improved access and increased accommodation which will shortly be provided, it may be fairly assumed that Bristol will yet regain to some extent a leading position among the ports of the kingdom.

The whole of the works executed since 1882 have been under the superintendence of Mr. John Ward Girdlestone, M. Inst. C.E., to whom the Author is indebted for permission to bring forward, and for assistance in preparing, this Paper.

The Paper is accompanied by three tracings, from which Plates 3 and 4 have been engraved.

[APPENDIX.

APPENDIX.

DETAILS of COST of WORK at ROUND POINT, 1883–85.

Total quantity of rock removed, 4,996 cubic yards = 8,730 tons.

		£	s.	d.	£	s.	d.	£	s.	d.
Plant:										
Engine-house, with air-compressing and electric-lighting plant, boiler, &c					1,184	0	0			
Two crane-barges, with steam-cranes, pumps, &c.					2,554	0	0			
Four rock-drills					232	0	0			
Tools					153	0	0			
					4,123	0	0			
Interest and depreciation, two years at 10 per cent. say								800	0	0
Repairs and renewals of plant:										
Engine house and machinery					62	18	10			
Crane-barges and machinery					133	5	9			
Rock-drills					53	18	5			
Tools, including sharpening drill-bits, &c.					128	7	4			
								378	10	4
Stores:										
Miscellaneous					118	15	2			
Coal (336 tons)					189	0	0			
Torch oil and cotton					49	14	6			
								357	9	8
Explosives:										
Dynamite, No. 1	600 lbs @	0	1	6	45	0	0			
Detonators	1,600 No „	0	2	6	2	0	0			
Blasting-powder	800 lbs „	1	17	0	14	16	0			
Double-tape safety fuse	235 coils „	0	0	8	7	16	8			
Gutta percha fuse	136 „ „	0	0	9	5	2	0			
								74	14	8
Wages:										
Rockmen					2,131	7	3			
Mudmen					698	11	5			
Watchmen, bargemen, &c					434	6	8			
								3,264	5	4
Total								4,875	0	0
Deduct value received for rock (7,560[1] tons @ 8*d*)								252	0	0
Net cost of work								4,623	0	0

Cost per cubic yard = 18*s*. 6*d*. Cost per ton = 10*s*. 7*d*.

---

[1] The remainder of the rock was used in building cross-walls to keep up the mud.

(*Students' Paper, No. 250.*)

"Flexible Wheel-bases of Railway Rolling-Stock."

By JAMES DENIS TWINBERROW,[1] Stud. Inst. C.E.

A DIFFERENCE of opinion appears to exist as to the desirability or otherwise of retaining the wheel-base of rolling-stock rigid with the vehicle. Some engineers consider that the extra cost incurred in the construction of bogies and radial appliances is not repaid by the lower cost of maintenance of road and car, or by dispensing with nearly 50 per cent. of the buffers and couplings, and increasing the carrying capacity per lineal foot and per ton dead-weight. These advantages might be secured by the general adoption of bogies under all descriptions of stock; but on the other hand, English railways have been laid out to suit the four-wheel wagon of 8 to 12 feet wheel-base, and 6 to 10½ tons carrying capacity, all "terminal facilities," hoists and tips, being adapted to this unscientific production; and thus a change in its design might be fraught with consequences too radical in their nature for the matured ideas of railway directors.

The thoroughness with which American engineers have adopted the idea of the flexible wheel-base has resulted in practically the whole of their stock being so fitted, thus enabling roads to be laid through an undeveloped country in a cheap manner, allowing the payment of dividends with comparatively small traffic receipts.

To obtain a correct rolling motion upon a curve it is necessary: First, that the outer wheel shall travel a distance greater than that described by the inside wheel by the amount the outer rails exceed in length the inner; that is, if independent rotation is impossible, their diameters must bear the same ratio as the radius of the curve of the outer rail to that of the inner. In practice this relation never obtains, but it is in some measure provided for by coning the treads of the tires, whereby the vehicle, flying to the outer rail in virtue of its centrifugal momentum, brings the larger periphery to bear on that rail.

---

[1] This communication was read and discussed at a meeting of the Students on the 8th of February, 1889, and was awarded a Miller Prize in the Session 1888-89.

Secondly, that the axles shall be enabled to set themselves radially to the curve, the planes of their wheels forming tangents; it is to approximate to this condition that the appliances now about to be described have been introduced.

In considering the magnitude of the losses due to this imperfection, it will be well to take a simple typical case of a six-wheeled vehicle, of total weight w, distributed as w_1, w_2 and w_3 on the leading, the centre, and the trailing-axles respectively; and let d be the length from the centre of the vehicle to the tread of the leading or trailing-wheels; let this vehicle travel at a rate of v feet per second round a curve of r feet radius.

If now in a certain time t the distance moved be vt feet, or $\frac{v\,t}{r} = \theta$ unit angles, then at the end of that time the vehicle will occupy a position at an angle θ with its former direction, and this change will have been accomplished by the lateral pressure at the flanges causing rotation about the centre, the treads of the wheels having to slide over the rails through a distance $d\,\theta$ for the leading and trailing, and $\frac{c\,\theta}{2}$ for the centre pair, $\frac{c}{2}$ being the half distance between the rail centres.

The force required to produce this motion will be evidently the weight × coefficient of friction between the rails and tire.

The work expended in displacing the leading and trailing ends is then

$$(w_1 + w_3)f.d.\theta,$$

and is accomplished in t seconds; but $t = \frac{\theta\,r}{v}$, hence, in one second, $\frac{(w_1 + w_3)\,f.d.v}{r}$ foot-lbs. of work are done against friction; to this must be added the work done on the centre pair, $\frac{w_2.f.c}{2\,r}$

Hence $\left(\text{putting } c' \text{ for } \frac{c}{2}\right)$ work is lost at the rate of

$$\frac{f\,.\,v\,\{(w_1 + w_3)\,d + w_2 c'\}}{r\,.\,550}\ \text{HP}.$$

This of course is subject to the assumption that the wheel treads are not coned, and that the frames are stiff enough to resist bending; it is evident that this formula includes the loss due to the equality of the diameters on the inner and outer rails.

At 60 miles an hour on a 10-chain curve, with a 45-ton engine whose weight is symmetrically distributed on a 16-foot wheel-base, the loss is 31 HP., the coefficient of friction being taken at 0·2.

This loss will be independent of any lateral play in the axle-boxes, provided the axles maintain their parallel position; but sliding axle-boxes are very useful in lessening the intensity of the lateral pressure, which must otherwise assume great magnitude in the case of engines whose leading wheels have inside bearings at a part where the frames are of maximum stiffness, that is, just behind the cylinders. In considering the additional loss of work due to this cause, it is necessary to note that the instantaneous centre of revolution is at the point of contact of wheel and rail; hence the radius at which work is done is very short, but it increases with the diameter of the wheel and the length of the engine's wheel-base, since these dimensions determine the point of contact of the flange and rail in advance of the tread of the tire. This affords an explanation for the preference usually exhibited for wheels of moderate diameter for leading and trailing purposes.

This loss may be reduced to a minimum by providing either axle with a radial box. In fact, flexibility at the trailing end appears to have much to recommend it; the extra bulk is not advisable beneath the cylinders or motion bars, whilst under or at the back of the firebox there would be no objection to its presence; the head of the engine would be kept into the curve instead of stretching across it, and the driving-axle would assume a more nearly radial position.

A third cause of increase of the flange pressure is the centrifugal force created by the momentum of the vehicle in virtue of its rotation about the centre of the curve. The centripetal resistance will act upon the flanges of the extreme wheels, whilst the centre ones bear against the inner rail as the engine lies across the curve; and for this reason the treads of the latter are usually turned to a flatter cone, or else parallel, whilst the flanges are thinned. The pressure thus induced may be calculated from the well-known formula $\frac{m v^2}{g r}$, m being the mass of the vehicle in lbs., 45 × 2,240 in the case of the engine before considered.

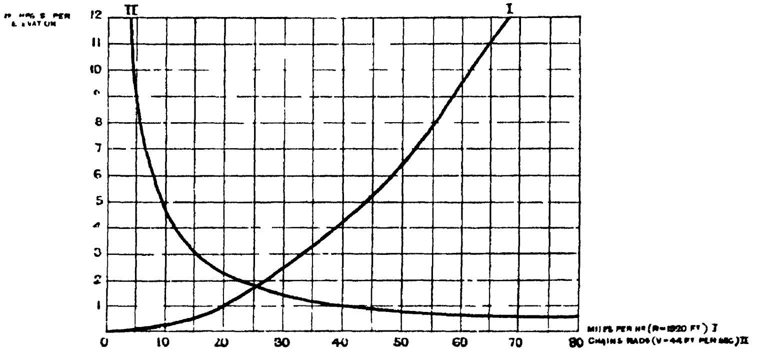
Under the severe conditions there imposed, this would attain a value of 36,960 lbs., nearly 17 tons; but since this varies as the square of the velocity and inversely as the radius, at 30 miles per hour and on a 20-chain curve, conditions more usual in practice, the value falls to 4,620 lbs.

But the centripetal resistance may be wholly provided for by cant-ing the rails so as to incline the centre line of the engine at an angle $= \tan^{-1} \frac{\text{centrifugal force}}{\text{mass of engine}}$ with the vertical. A simple diagram will make this clear.

For a speed of 30 miles an hour, and 20 chains radius, the angle becomes $\tan^{-1} \frac{4{,}620}{45 \times 2{,}240} = \tan^{-1} \frac{1}{21 \cdot 8}$; hence, under these conditions a super-elevation of $2\frac{3}{8}$ inches on the outer rail will entirely relieve the flange pressure due to centrifugal force; but it is evident that in practice the cant is never sufficiently great to relieve the pressure induced by high velocities and small curvature.

It is easy to plot a curve to denote the increase of super-elevation with (i) varying velocity, (ii) varying radius of curvature; plotting values of the tangent of the angle of cant on the axis of y, and the values of the velocity on that of x, a curve is obtained governed by the relation $y \propto x^2$, hence a parabola, with axis vertical. Taking r as the variable, the result is a curve whose locus is $y = \frac{v^2}{g \cdot r}$, that is, an hyperbola, when v is constant.

FIG. 1.



Although one great cause of loss of work cannot be obviated by any system of lateral freedom that maintains the axles in parallel positions, sliding-boxes for the leading wheels of express engines have found much favour in this country and on the continent, as they constitute a simple means of mitigating the otherwise severe stresses due to the lateral rigidity of the frames. The axle-boxes are usually placed on journals outside the wheels, and are of ordinary type except that the flanges are from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch clear of the horn-blocks, whilst their tops are formed to inclined planes meeting in a ridge at the centre, upon which is a solid cover, provided with flanges fitting close to the horns. Upon this the spring pillar rests, and will evidently be wedged up when the axle-box moves to either side of its central position, thus bringing an increased weight to bear upon it, and forcing the cover home to its seat as the disturbing force ceases to act.

The same system of wedges has been used to control four-wheel bogies; they are called, from the name of their inventor, Bissell inclines. The chief objection to their use is that at high speeds the return of the top planes to their lowest position is accompanied by a sharp blow, liable to loosen rivets and distort the framing; the disturbance in the distribution of the weight is also an undesirable feature.

Occasionally angled horn-blocks have been provided to enable the axle to set radially to the curve, but being hard to fit and reface they are not so usual as the plain parallel type.

The radiating appliance for single axles, as used in America, is known as the pony-truck, and consists of two ordinary axle-boxes sliding in guides attached to a short frame that forms the base of an isosceles triangle, whose apex is towards the centre of the engine, and is secured by a pin on the centre line.

The truck in use on the Canadian Pacific Railroad is constructed of two slabs, united at their ends by horizontal pieces resting on spiral springs, two being provided for each box; the cross slabs sustain the weight by pairs of links inclining downwards and towards one another, connected at their lower ends to a casting which is prolonged upwards through a guide attached to the main frames; from the top of this casting a bolt passes vertically down, bearing in an eye the leading end of an equilibrium lever, which is attached at its other extremity to the hangers of the front driver springs. As the truck moves laterally beneath the main frames, the upper ends of the links move in a horizontal plane, while their lower ends, being pinned to a casting that can only rotate on a vertical axis, tend to make the upper ends traverse arcs of circles, the outside one rising above the horizontal, the inside one falling below it. Thus if all pins are a tight fit no motion can take place without tilting the engine over towards the outside of the curve, or lifting the outer wheel of the truck; but if the pins are free to "give" when not in tension, then the weight will be entirely transmitted by the inside link and the greater load imposed on the inner wheel; also the tension in this link, acting in an inclined direction towards the centre of the engine, will, by its horizontally resolved component, draw the truck back to its central position, when the pressure on the outside flange ceases.

It is more general in American practice to find the links placed divergent towards their lower ends; this method secures the advantage of greater weight on the outside wheel on curves, hence the liability to mount the rail is lessened. The centralizing effect is the same in both cases.

The truck in use on the Pennsylvania Railroad carries the weight by means of vertical links attached to the extremities of a pair of transverse plate springs; the links are formed with a T head, through which two bolts pass and bear on an appropriate casting; each link then is virtually equal to two, one being inclined to, the other from, the centre. Thus the weight is always equally distributed on the axle, and smoother action is likely to result. This is the type of truck used under the Mogul engines on the Great Eastern Railway, but without conspicuous success, as, probably owing to the transverse springs, it is unable to control the "shouldering" set up by the action of the steam in the wide-spread cylinders.

In the bogie adopted by Mr. Hurry Riches on the Taff Vale line, double sets of links are provided, so that there is always a parallel pair to transmit the weight symmetrically to the axles.

One fault in the action of the pony-truck is that the axle, in swinging about the pivot, displaces its centre line, so that the centre of the bolster casting is no longer vertically over it, and as the bottom ends of the inclined link rotate with this casting, whilst the top swing with the axle, the want of alignment must be met by slackness of fit and the end play of the links on their pins; thus wearing surfaces are exposed to dust and racking strains are introduced. A cushion of rubber is sometimes interposed to permit of greater freedom.

The single-axle truck, known in England as the radial axle-box, owes its present neat form to Mr. F. W. Webb. As adopted by Mr. T. W. Worsdell, it consists of a deep cast-iron trough, curved to a radius of 13 feet, inverted and provided at the ends with brasses fitting the axle-journals, each 11 inches long; it is placed between guides flanged from $\frac{7}{8}$ inch steel plate and cold-riveted to the frames. These guides are stayed at the top and bottom, the stays in the latter position carrying an elliptical check-spring of four plates to each side. Pins attached to the box just below the journals bear against the buckles, and compress the spring against projections on the stay carrying it, by an amount equal to the travel of the box in the guides; the weight is transmitted by spring pillars standing on case-hardened feet, capable of sliding on grooves formed on the top of the box.

The objection to these radial axle-boxes is, that they add considerably to the weight not carried by springs; they are also usually formed to a radius too long for perfect action.

A consideration of the natural arrangement of the wheel-base on curves will demonstrate the most desirable radius, and the conditions necessary for a bogie to fulfil.

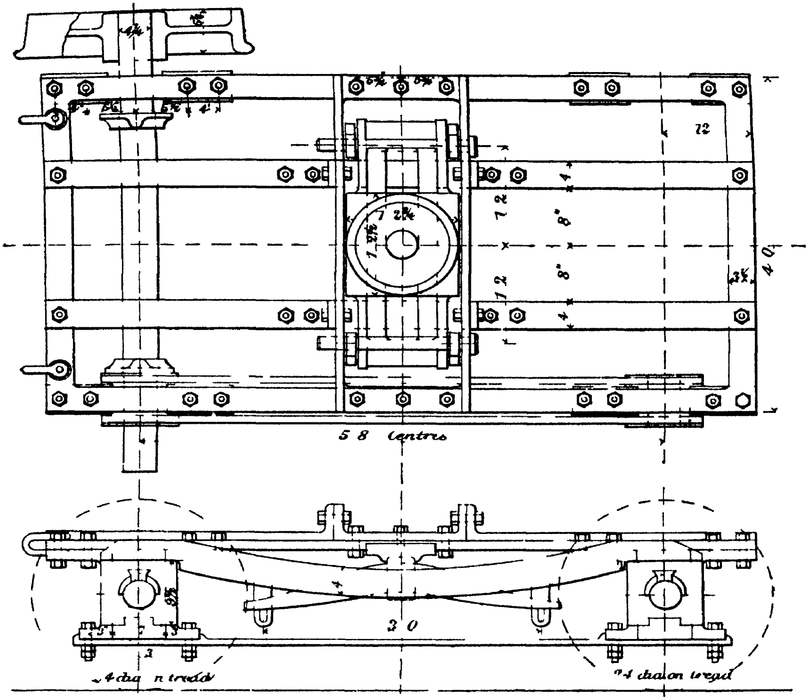
Let A be the centre of the rigid wheel-base, and B that of the bogie or radial box; in finding the position of least resistance, the centre line of the engine will become tangent to that of the curve at A; similarly, the centre line of the bogie tends to the tangent at B; the two centre lines intersect at C, midway between A and B. And the angle through which B has turned will be equal to $\frac{\text{arc A B}}{\text{radius of curve}}$; hence, if the centre guide be formed to the radius CB, no provision being made for rotation about the centre, perfect action would result; but upon entering a reverse curve C would fall inside it, hence CB could not be a tangent, and rotation about the centre is necessary in order to bring C virtually outside the new curve.

In American four-wheel bogies, the lateral play is controlled by inclined links as described in the case of the pony-truck; whilst the centre-piece is similar, but somewhat increased in size. The Standard Pennsylvania Railroad truck, Figs. 2, may be taken as typical of the class.

It will be noticed that the bogie consists of a rectangular frame, welded solid, of bars 3½ inches by 1½ inch, to the lower surface of which horn-blocks or pedestals are bolted, Fig. 3. No bracing whatever is introduced to keep the frame square, but two flat bars, 4 inches by 1 inch, spaced 1 foot 4 inches apart, run from front to back. In no case are the joints checked on to one another, so that the 1-inch bolts take all the strain, and are liable to become slack and to wear oval holes in the framing. No provision is made for increasing the strength where the holes are drilled; thus the joints are about 25 per cent. weaker than the remainder of the bars.

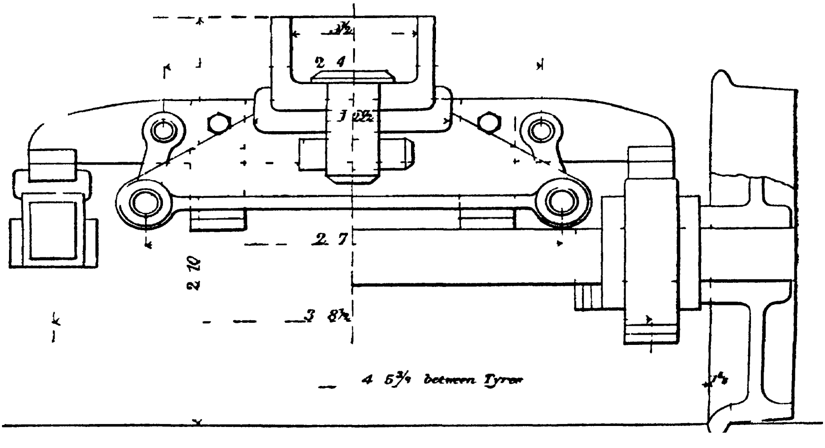
The journals are 7½ inches long by 4¼ inches in diameter, and the axles, in accordance with American practice, are plain parallel without the usual solid forged collars to transmit the lateral pressure, but which, it may be added, waste much oil by throwing it off at high speeds from their larger diameter, and cause an interruption in the modulus of elasticity of the axle. There is an inverted spring to each side of the bogie, as in England, supporting the weight at its centre, and hanging by its extremities to girders spanning the axle-boxes. The spring hangers are extremely

FIGS 2



STANDARD ENGINE-TRUCK, PENNSYLVANIA RAILROAD

FIG. 3.



primitive in form, being merely flat bars passing through slots in the ends of the springs, which have to be reinforced by keeping several of the plates to the full length. This, together with the reverse curvature adopted, tends to destroy the true spring action of uniform flexibility; a cotter through the lower end of the hanger transmits the weight.

The spring girders have a long bearing on the top of the axle-box, so that when one box rises independently, the load is taken by its inner top corners alone, introducing a tendency to turn the box in the horns, and to cause severe local pressure on the rubbing-surfaces at diagonally opposite corners. The one good feature to be observed is that the various centre lines of the frame, horn-blocks, journal and spring, are in one vertical plane.

The "Swing-bar" bogie has been adopted on the Great Southern and Western Railway of Ireland, and on a few British lines; but in all cases it has been constructed with plate frames. In some examples two conical bearing springs have been fitted to each box, neatly abutting on brackets cast with the horn-blocks; but it is doubtful if this type of spring is a desirable acquisition.

The simplest English bogie is perhaps that used under Mr. Stirling's express engines. The frames are 1 inch thick, spaced 4 feet 0½ inch apart, and stayed by four cross-stays, 1 foot 3½ inches to each side of both axles; a cover-plate over the axles, secured by angle-iron, gives ample resistance to racking strains. Two plate stays 9 inches apart connect the centres of the two inner transverse stays, and carry a block bored out to receive a pin rigidly attached to the engine frames by an arrangement of plate, rivets, and angle-iron. This pin is placed 3 inches behind the centre of the bogie; thus, the wheel-base being 6 feet 6 inches, the leading-wheels have one-seventh less load than the trailing-wheels, which secures the advantage of gradual displacement and compression of the road as the increasing loads are applied; also, for the same angular movement, the leading-wheels traverse a greater arc than the trailing-wheels, which is important, inasmuch as no provision is made for lateral play; nevertheless, such bogies cannot give results markedly superior to those obtainable with a rigid wheel-base. A separate spring is provided to each box, hence the load has to be transmitted radially from the centre to each hanger, an office for which the rectangular framing is ill fitted; but the evil is mitigated by carrying a portion of the load on brass steadying-plates on the top of the bogie frames at the centre.

The Adams bogie successfully overcomes most of the objections urged against the foregoing type. As used on the London and

South-Western Railway, the frames are formed of 1¼-inch plates, stayed 2 feet 6 inches apart by two transverse channel pieces, riveted top and bottom to plates attached by angle-iron to the frames; rubbing-pieces are attached to the upper surface and vertical faces of these channel bars; and on the parallel guide thus formed there rests a cast-iron block or saddle, bored out in the centre to receive a hollow cast-iron trunnion, 7½ inches in diameter, bolted to a horizontal plate-stay, riveted to the frames beneath the cylinders; the lower surface of the latter stay is faced to bear on the top of the saddle, thus providing a second rubbing-surface, subject to rotation about the centre, while the former permits of a transverse rectilinear travel.

An inverted spring on each side transmits the weight to a pair of girders fitted at their extremities with cast-iron blocks, having a transverse, semi-cylindrical recess on their lower faces; convex projections, cast on the top of the axle-boxes, fit into these, and thus allow great freedom of movement.

The lateral play of the bogie is controlled by plate springs of 2½ feet span, bearing with their buckles against the saddle, and having their extremities formed to slide against the bogie frames, thus tending to maintain a constant distance between the two.

As this bogie was designed before the general introduction of cast steel into locomotive construction there is a large amount of riveting. This is undesirable, as the constant vibration tends to loosen rivets that have been closed hot; on cooling they fail to fill the hole, and have only the friction, induced by their state of tension, to depend upon to keep the joint absolutely tight; on the other hand, cold-riveting necessitates counter-sunk holes, turned rivets, and expensive labour to close them.

The frames are unnecessarily thick. Since the weight is carried direct from the centre of the spring, and is transmitted merely through the transverse channel-pieces, it is difficult to see what stresses can be brought to bear upon them sufficient to justify so lavish a distribution of material.

A bogie, constructed on a similar principle to the above, is in use on the Caledonian Railway; the frames are arranged with the horn-blocks outside, and are stayed by a single casting having a transverse channel in its centre, and ribbed so as to form an inverted U on each side of it. The upper faces of the latter are planed to form the rubbing-surface for the reception of the saddle, the lateral play being controlled by an outwardly curved spring on either side, and the tension adjusted by nuts on the hangers that pass back through appropriate brackets. The centre pin is attached to a plate 1 inch thick placed beneath the main frames, and riveted thereto by angle-iron. The whole is characterized by the neatness and simplicity of design that should always be the leading feature in locomotive construction. The central casting is of a form readily moulded, and yet of such shape that distortion is not probable, whilst a minimum amount of labour is required in fitting the whole together.

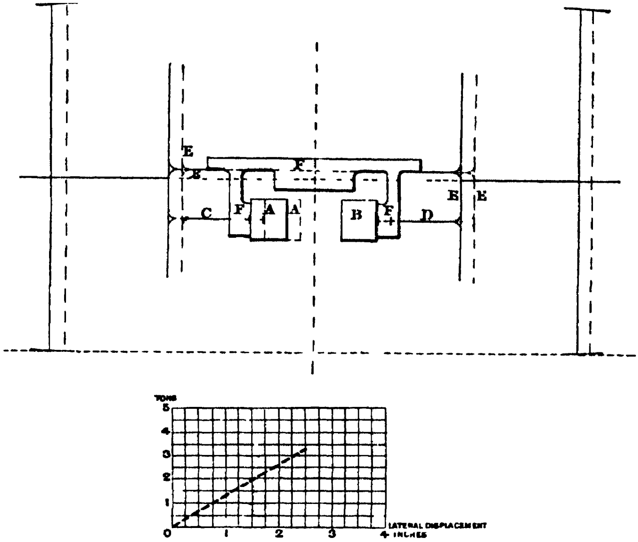
When the lateral movement is rectilinear, the whole of the necessary angular displacement must be obtained by rotation about the centre pin; this is accompanied by much frictional resistance, as the bearing surfaces are of large diameter, which necessitates a considerable pressure on the flanges of the trailing-wheels to bring the bogie back on leaving a curve, thus tending to lurching and unsteadiness. To obviate this, a bogie with a curved centre guide is used under the compound express engines of the North-Eastern Railway Company; but this guide is formed to a radius about the centre of the driving-axle, hence partial rotation on every curve is still necessary.

This bogie is constructed practically entirely of steel, with $\frac{5}{8}$-inch frames, spaced 2 feet 8 inches apart, and stayed by two strong steel castings with concave and convex faces, forming the centre guide for the saddle. The saddle embraces by lugs on its lower side an elliptical check-spring of 2 feet 6 inches span, against the buckles of which pins 2 inches in diameter, bolted to the inner side of the bogie-frames, abut and compress the spring against the opposite lug on the saddle when any lateral movement takes place. The spring is supported by a stay placed between the curved faces at the bottom; all the rivets in the frame are of Lowmoor iron, turned to a driving fit and closed cold.

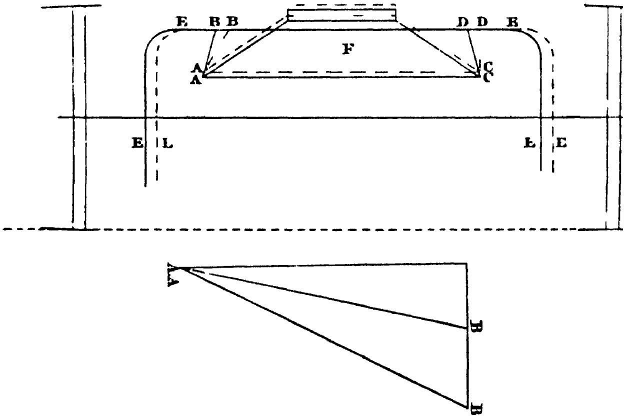
The advantage of the elliptical spring is that the same force produces double deflection without a corresponding diminution of strength. Figs. 4 and 5 show the lateral force necessary to produce the varying deflections in the case of the bogie with inclined links, and this spring-controlled arrangement.

An extremely light and original form of bogie is in use on the Thylands Railway in Denmark, under the trailing end of four-wheel coupled tank-engines. It is not provided with any centre pin or lateral guide, but is caused to follow an approximately circular path by means of two horizontal links that connect it to the main frames, and so draw the bogie along. These links are inclined, the pins connecting them to the main frames being outside of those attached to the bogie frame, and further apart. Were these links parallel, the cross-centre line of the bogie, and the line at right-angles to the frame, would always be parallel, whatever the amount of lateral disturbance; but, being

Figs. 4.



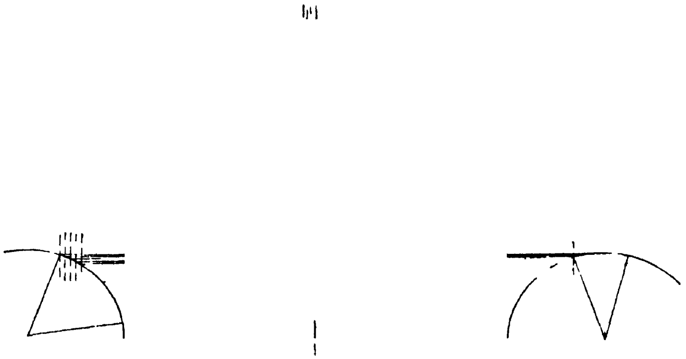
Figs. 5.



Minimum righting effort, 4⅛ tons; righting effort at 1¼ inch displacement, 9 tons.

inclined, any such movement induces a rotative one about the centre; hence by properly proportioning the length of the links and their inclination, that motion is obtained which theory shows is required. It is apparent, Fig. 6, that the locus of the centre of the bogie is a curve convex towards the centre of the engine, hence it is drawn outwards when laterally displaced, but for moderate travel this is not serious, whilst an amount of angular motion can be obtained to correspond to the magnitude of the lateral play. In detail, the bogie presents no special feature except the provision of a transverse beam for equalizing the weight upon the two side-springs, an arrangement that adds considerably to the weight, increases the stresses on the framing, and renders the engine more liable to roll on a bad road; as the weight is transmitted by the engine frames to sliding-shoes at the four corners, full advantage might be taken to reduce it to a minimum, and thus remove the most powerful objection to the use of a bogie beneath an already ponderous machine.

Fig. 6.



Lines, dot and dash, denote positions of longitudinal centre line of radial bogie.
Continuous lines ,, ,, transverse , Thylands Railway bogie.
The deflections being in opposite directions.

Flexibility of the wheel-base is usually obtained in passenger stock by a bogie at either end of the vehicle, in the case of American cars the total depth from the window-sill to under-frame being used as a stiff truss to span the distance between the centres; but the body-framing of English carriages, being a series of parallelograms with open spaces for the doors, is of course useless for the purpose, and under-trusses have been resorted to. On the London and North-Western Railway, carriages are constructed with a four-wheel rigid base of moderate length, and a pair of wheels with radial boxes at either end. Many British Railway Companies retain the six-wheel carriage as their standard.

This cannot be ranked as a flexible arrangement, as the only attempt to meet this desideratum is made by allowing the centre pair of wheels to move laterally, and thus relieve the under-frame of strains that would otherwise quickly ruin it. The centres of the extreme wheels are 21 feet apart, hence it is not surprising that where such are in vogue guard-rails, and special chairs with tie-rods, &c., are freely used on moderate curves; whereas heavy American sleeping-cars are safe on roads whose only lateral resistance is that afforded by two small spikes per sleeper. The Great Northern Railway Company is using a rigid wheel-base of 32 feet 9 inches under passenger coaches.

The four-wheel bogie is not now put under many passenger-cars, as, in case of one wheel meeting a depression or interruption, the bogie remains supported on three points alone, with its centre of gravity on the line joining two of them; hence it is in unstable equilibrium. The use of six wheels gets over this, but of course adds to the weight and cost. The bogie adopted on the Midland Railway is provided with three pairs of wheels, 37 inches in diameter, spaced 5 feet 3 inches apart from centre to centre. The axle-boxes are outside, and spanned by girders, cranked down and carrying helical springs, spaced so that each one distributes half the load on one side, in the ratio of 2 to 1, between the end and centre wheels; thus equal loading is obtained. In the more recent designs this arrangement has been supplanted by an independent laminated spring to each box. The springs carry the main frames, of wood flitched with iron plates, which are stayed at the ends and also at each side of the centre wheels, the latter stays being provided with links inclined downwards and outwards, and coupled at their lower ends to a bolster that supports a pair of transverse elliptical springs at either end. On these rests a bolster of H form, built up of heavy timbers and flitch-plates, and carrying at its centre a concave casting for the reception of the centre pin attached to the under-frame of the carriage.

A few wagons for special purposes, fitted with double bogies, form the only specimens of English goods stock with flexible wheel-base; practically the whole of the stock is of the same type as that in vogue forty years ago, the only improvements being embodied in the use of improved material and greater scantling of parts. In striking contrast to these cumbersome wagons are the neat Goodfellow and Cushman freight-cars lately introduced from America. In addition to the special features of their tubular under-frame, the simple construction of the bogies will repay consideration. Near either end of the car is a transverse trussed beam, carrying at its lower surface in the centre a concave casting. This casting is curved to a small radius, for the reception of a similar convex casting mounted on the top of the bogie bolster, supported at its extremities by helical springs seated on the ends of the tie forming the transverse connection between the bogie frames. The latter are formed each of two triangles of bar-iron, their bases being vertical on each side of the spring, and connected by a solid continuation of the sides above and below; the apices are elongated, and rest upon the top of the axle-boxes, to which they are attached by bolts on each side, passing down through a horizontal tie beneath the boxes.

The triangular framing adopted dispenses with "bending moments" in its component parts; the stresses may thus be easily estimated, and economical sections provided; there are no horn-plates or rubbing-surfaces to wear or get set out of truth, whilst the removal of a single bolt on each side allows the axle with its boxes to be rolled out and removed for repair or for examination.

This arrangement of double bogies is probably the best possible for carriages and wagons, as by placing them near the ends, the centre line of the vehicle forms a chord to the arc of the curve, so that the buffer beams do not project so far towards the outside as they would do in the case of a long vehicle forming approximately a tangent at its centre point. A single central buffer would also be preferable.

Mr. M. N. Forney gives the following information respecting some American freight-cars:—

	Feet.		Lbs		Lbs
Flat car, length,	34;	weight,	16,000	to	19,000
Box " "	34;	"	22,000	"	27,000
Meat " "	30 to 34;	"	28,000	"	34,000

The average weight of the American covered freight-car may be taken at 23,000 lbs., capable of loading 50,000 lbs. freight, or $\frac{1}{2\cdot13}$ ratio of dead to live load; a total weight of 73,000 lbs. on four axles, with slight possibility of any one getting undue load. To carry an equivalent quantity of ordinary freight, three English wagons would be required with a dead weight of 34,000 lbs., giving a ratio of $\frac{1}{1\cdot5}$ nearly, a total weight of 84,000 lbs. on six axles, being a less weight per axle, but, owing to the increased liability of unequal loading and severe flange-pressure aiding the outside bearings in producing severe bending moment, requiring a stronger axle. There will also be three sets of brake-work, six sets of buffers and draw-gear, as against a double set in the former case; twelve carrying springs against four of stronger type; 50 feet of train-length against 38 feet, and probably 25 per cent. greater tractive force required.

The weights of the English four-wheel wagons often far exceed that given above; mineral wagons of 23,520 lbs. capacity weigh about 15,000 lbs. with a wheel-base often exceeding 9 feet; wagons of certain types occasionally run up to 17,496 lbs. dead-weight for a possible load of 17,920 lbs. (8 tons). Articles whose length much exceeds 16 feet require an empty wagon to run beneath their projecting part, to prevent possible contact with the load of a following vehicle.

So long as the present high speeds, light trains with large proportion of dead weight, and costly repairs and renewals prevail, so long will English Railway Companies find it impossible to handle heavy freight in volume at low rates.

The Author begs to acknowledge his indebtedness to Mr. M. R. Jefferds, for information respecting the Goodfellow and Cushman freight-cars, to which reference has been made above.

The Paper is accompanied by several diagrams and tracings, from which the Figs. in the text have been engraved.

(*Students' Paper No. 245.*)

"Experiments on the Strain in the Outer Layers of Cast-Iron and Steel Beams."

By EDWARD CARSTENSEN DE SEGUNDO,[1] Stud. Inst. C.E.

IT was the Author's intention to describe these experiments in sufficient detail to enable any of the results upon which the opinions set forth in the Paper are based, to be verified by reference to the text and to the Appendix. The Author found, however, that under these circumstances the Paper would assume prohibitive dimensions, and he has been led to omit all but the absolutely necessary detail.

As is well known, the values yielded by the ordinary formula for the strength of beams are not in accord with the results of practice, and this is the case for all kinds of material. The strength of a beam, as determined practically, is invariably greater than its theoretical strength; it is therefore necessary that if the stress does vary as the bending moment throughout the span, either the material is capable of enduring a higher stress before rupture in virtue of being molecularly connected to less stressed material, or the material in the most stressed layer of a beam will ultimately only endure a stress equal to its tensile ultimate stress, and the formula itself is defective. It can be shown that the first alternative is theoretically incorrect,[2] and it remains to be shown experimentally whether the second alternative obtains or not. For reasons above mentioned, the Author cannot discuss the various theories which have been built up to account for the anomaly; it will suffice to say that the Author entertains Mr. Claxton Fidler's view that, as yet, no satisfactory explanation has been offered.

---

[1] This communication was read and discussed at a Meeting of the Students on the 16th of November, 1888, and was awarded The Miller Scholarship in the Session 1888–89

[2] "A Practical Treatise on Bridge-Construction," by T Claxton-Fidler, M. Inst. C E. 1887.

Inasmuch as, in practice, the material in a structure is so disposed that the maximum stress in any part is well within the stress at which the limit of elasticity occurs, it might be contended that, if the formula give correct values within the limit of elasticity, it is as much as would ever be required of it in practice. Unfortunately, the limit of elasticity (Bauschinger's definition), in a beam of ductile material, is reached at a calculated stress which is found to bear a similar ratio to that at which the limit is reached in pure tension, as the theoretic rupture-stress to the fracture-stress. Hence it would appear that the sources of error in the formula become appreciable even before the limit of elasticity is reached in a beam. The discrepancy in the value of the stress at the observed limit of elasticity in bending is, in the Author's opinion, due to a wholly different cause to that to which the discrepancy in the ultimate stresses is to be ascribed. For were the limit of elasticity of a beam to be observed at the load which corresponds to a stress in the outer layer equal to that at which the limit in pure tension is reached, it would be necessary that, ultimately, planes originally parallel to the lines of application of the forces acting on the beam, would assume a form more or less resembling the stress-strain tensile-curve of the material, according to the position of the chosen plane in the span. This, however, is not the case; for, even in the neighbourhood of the fracture of a broken beam, the Author has observed that originally plane sections, although taking up a shape in accordance with Mr. Barré de St. Venant's theory, cannot be said to approach the form of the stress-strain tensile-curve, and the curvature of these planes is not visible until the material is very distressed. Thus no such condition as a period of increasing strain in the outer fibre of a beam without increase of load can possibly obtain as in pure tension;[1] hence the load, which would cause the deflection of the beam to increase in a manner out of all proportion to the increase of load, would be such as to cause the whole area of the section, except a narrow zone, to be gradually stressed to the limit of elasticity. This load would, of necessity, be higher than that at which the maximum stress in the section reached that corresponding to the tensile limit of elasticity.[1]

---

[1] The period of further extension without any increment of load, which is almost always observed in the tensile stress-strain curve, is possibly due to the following circumstances. A longitudinal extension is accompanied by a longitudinal separation of the molecules proportional to e, the extension, and a simultaneous inward pressure. On the distance between the molecules longitudinally being increased, the tendency for the molecules to be drawn in to fill the space must also increase. Now, should the load be released before the extension has been sufficiently great to admit of a complete transverse molecular flow, the power of cohesion will be able to assert itself in reducing the elongation of the piece. As the piece approaches its original length, an apparently permanent set would be observed, due to the squeezing out of the transversely intruded molecules not being fully accomplished. This, however,

The foregoing remarks apply to ductile material. Such material as cast-iron has no limit of elasticity in the true sense of the word. In the Appendix (Table I, experiments A and B) will be found the details of an experiment on a cast-iron test-piece, designed to show if, at any point throughout the tensile life of the material, there was any indication of a limit of elasticity as defined by Bauschinger. It will be seen that, although the strains corresponding to the increments of load were measured by so delicate an instrument as Professor Kennedy's extensometer to within a few lbs. of the ultimate load, there is no irregularity in the stress-strain curve which could be pointed to as the limit of elasticity.[2] An examination of the elastic stress-strain curve yielded by this test-piece shows that the modulus of tensile elasticity diminishes very rapidly. The relation between stress and strain is practically expressed as follows:—

---

would only be a matter of time. At the point of breakdown the distance of the molecules longitudinally must have increased sufficiently to allow of a transverse flow of molecules taking place completely, in which case a permanent elongation would result. It is evident that this flow cannot take place over every section throughout the whole length of the piece, and it probably takes place at or in the neighbourhood of the section at which ultimately fracture ensues. The position of this section depends upon the accuracy of the testing machine, and upon the degree of homogeneity of the material.

[1] Apart from the difficulty of determining theoretically the limit of elasticity, it should also be borne in mind that the observed limit is influenced by many circumstances, such as the process of manufacture, and the subsequent treatment of the material. Thus, as is well known, a piece cut from the flange of a rolled joist yields at a less load than a piece cut from the web, and the strength with the grain is different to that across the grain. Both the rectangular bar and the rolled joist which were experimented on were so twisted when they arrived from Middlesborough that it was necessary to have them straightened before any machining could be proceeded with. This naturally involves a stress in various directions greater than the limit of elasticity. Thus the limit, as observed experimentally, is by no means the first and true limit; and it becomes a question whether, in comparing the limit of elasticity of a beam (as obtained from deflection observations) with the limit obtained by testing in pure tension even a piece cut from the beam, it is not, in some cases, attempted to compare what is strictly speaking not comparable.

[2] The subsequent experiment, designed to show the molecular reconstruction of the material by rest, also shows that the last load at which the strain was measured in the first experiment must have been literally within a few lbs. of the breaking load (Table I, Experiment C).

Let E = the strain in 1,000ths of an inch, P = the stress in lbs. per square inch, then $E = P\,\{(0\cdot00081) + (0\cdot00001)\,(P - 2{,}000)\}$, the equation to the curve being $\frac{d^2x}{dy^2}$ = constant.

It follows from this that the neutral or unstrained layer of a cast-iron beam cannot always pass through the centre of gravity of the section, for it is well known that the compressive stress-strain curve of cast-iron is practically a straight line.[1] Thus the ordinary formula, which assumes that the moment of the compressed area about the neutral plane is equal to the moment of the extended area, must of necessity be inaccurate.

It has been observed that originally plane cross sections of a beam of ductile material remain practically plane, after flexure; whether this is so or not in the case of cast-iron it is difficult to say absolutely, for although the Author attempted to investigate this, his efforts were necessarily limited owing to the nature of that metal. At a very high load, however, the Author could not detect any curvature of lines which had been scribed on the machined surface of the cast-iron beam under experiment. Assuming, therefore, that for practical purposes, at least, the strains throughout the section of a beam vary as the distance from the unstrained layer, it at once follows that whether the stress varies in like proportion or not will depend entirely on the degree of constancy of the moduli of elasticity. The following Table gives

Stress.	Instantaneous Modulus Tension.	Stress.	Instantaneous Modulus Tension.
Lbs. per Square Inch.	Lbs. per Square Inch.	Lbs per Square Inch.	Lbs. per Square Inch.
2,000			9,390,000
	12,500,000	16,000	
4,000			9,520,000
	12,500,000	18,000	
6,000			8,930,000
	11,100,000	20,000	
8,000			8,420,000
	10,800,000	22,000	
10,000			8,218,000
	10,000,000	24,000	
12,000			7,844,000
	9,758,000	25,000	
14,000			

---

[1] Two experiments made by the Author in this direction corroborate this (Appendix, Table I, experiment D, and the second Table of the "Supplementary Experiments on Cast-Iron").

the instantaneous modulus of elasticity in tension of a cast-iron test-piece cast from the same ladle as the beam in question from which the serious degree to which the assumptions made in the ordinary beam formula are impaired, in the case of cast-iron, is apparent.

From this it follows that the stress corresponding to half the strain on the outer layer is more than half the stress in the outer layer, and so forth, as the following Table shows :—

Distance from neutral layer.	Stress in Lbs. per Square Inch.	Percentage of stress in outer layer.	Ditto according to Hooke's Law.
Maximum.	25,000	100·00	100·00
¾ „	19,900	79·60	75·00
½ „	14,100	56·40	50·00
¼ „	7,800	31·20	25·00
⅛ „	4,200	16·80	12·50

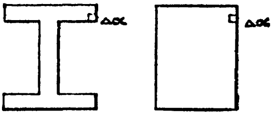
The shifting of the neutral plane, which of necessity occurs, owing to the inconstancy of the tensile modulus, and the constancy of the compressive modulus of cast-iron, would of course alter the area of the section which resists by tension; and it is perhaps worthy of notice that the percentage of increase of area of the equivalent figure in tension for a given percentage of displacement of the neutral layer in beams of equal sectional area, but of different forms, is similar to the increase of the discrepancy at the ultimate stress for corresponding sections, as will be seen by the following Table.

Form of Section.	Proportionate Increment of Equivalent Figure of Equal Percentage of Displacement of Neutral Axis.	$\frac{\text{Area of Section}}{\text{Area of Equivalent Figure}}$
I	1·00	1·33
▯	2·05	2·00
○	2·50	2·33

Cast-iron beams of these sections would invariably, under normal circumstances, fail on the tension side.

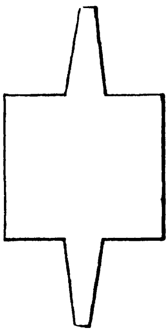
A question, naturally suggested in regard to the tacit assumptions made in the ordinary formula for beams, is whether it is justifiable to suppose that an elemental area in any part of the section offers a resistance which depends only on its absolute position in the section, and is not affected by the position it is in relative to the distribution of metal throughout the section; thus the elemental areas Δa, $\Delta a'$ (Fig. 1), are by the formula supposed to be of equal value in resisting the bending action of the load on the beam. This is manifestly inaccurate, as the flanges of a girder are under somewhat similar conditions, when the beam is loaded, to those under which Mr. Barlow's well-known experimental plate was tested. This fact the Author has further shown experimentally, by measurement of the strains along the centre, and along the edge of the flange of a girder.[1]

FIG 1



That the assumption above mentioned is unreasonable seems to be clearly shown by the following consideration: The modulus of the section (which, other conditions being equal, is a measure of the strength of a beam) of a beam of 3 inches square cross section is 4·5. If, however, a rib be affixed of the dimensions in Fig. 2, the value of this modulus sinks to 3·64. Thus the anomalous result is obtained that, although the material in the beam has been increased, and the beam considerably stiffened, according to the ordinary formula the beam is weakened. Pushing this to a logical conclusion, the strength of a beam may be reduced almost to zero by a sufficiently deep rib. Without entering into a discussion as to what would happen were a beam with two very deep ribs tested practically, it may safely be said that the theoretical formula fails in this instance because of its inapplicability to the case. It is interesting to note that this type of section is similar to the cruciform, in which the discrepancy between the formula and practice is greatest, while the inverse type of section, namely, the girder section, is the one which yields results most nearly in accordance with the formula. A little consideration will show that this is so because, during flexure, the material throughout the girder section is

FIG 2.



¼ full size.

Appendix, Table II.

stressed in a manner complying more than is the case in any other forms of cross section, with the assumptions included by the formula. Thus the Author risks little danger of contradiction in asserting that the form of cross section influences the distribution of stress throughout the section, particularly at high stresses, and that this fails to be taken into consideration by the ordinary formula. The fact, that the ratio of the bending moment to the modulus of the section is not necessarily an accurate measure of the stress existing in the outer fibres of a beam, is demonstrated by the following consideration. The formula for the deflection of a beam is

$$\delta = \frac{1}{12} \frac{S L^2}{E y},$$

where $S = \frac{M}{z}$,

L = span,
E = modulus of elasticity in tension,
y = distance of centre of gravity of section from the fibres in tension.

Consider two cast-iron beams of double tee, with equal flanges and of rectangular section, each 3 inches deep, cast from the same ladle and tested on the same span. Here $S L E$ and y are the same in each case,[1] therefore, according to the formula the ultimate deflection should also be equal in each case, which is well known not to be.

Arguing from the principle of work, the following formula is easily obtained for a rectangular section:—

$$\text{Strain} = \sqrt{\frac{2 W \delta L (1 + a)}{b d E_T (a^3 \beta + 1)}} = \kappa \sqrt{W \delta}.$$

where

W = load,	E_T = modulus of elasticity in tension;
δ = deflection,	a = ratio of specific compression to specific extension;
L = span,	
b = breadth,	β = ratio of compression modulus to tensile modulus.
d = depth,	
κ = a constant.	

The degree to which the calculated values of the strain on the outer fibres of a rectangular bar of cast-iron agree with those experimentally determined, will be seen from Table III in the Appendix.

---

[1] The fact that S is the same in each case is shown experimentally, and referred to in the description of the experiments (Appendix, Table VI).

MEASUREMENTS OF THE STRAIN IN THE OUTER LAYERS OF BEAMS.

In order to ascertain in how far the conditions assumed in the formula were realized in practice, the Author, in January and February, 1886, made a large number of experiments, with the above-mentioned object, on a cast-iron bar,[1] whose finished size was 63 inches by 2 inches by 1 inch.[2] Three test-pieces were also cast at the same time for the determination of the modulus of elasticity and ultimate strength. The apparatus, employed for the measurement of the strains of the outer fibre, was arranged to indicate the increment of the arc. The mechanism was of extreme simplicity, and the exaggeration was attained by an arrangement exactly similar to that employed in the Ashcroft Autographic Extension gear.[3] It is, therefore, not necessary to enter into constructive detail, and it will only be pointed out that it was determined that no fictitious extension, due to the moving parts of the gear, existed in the scale-readings.

The beam was treated in two ways. It was tested as 2 inches deep and 1 inch broad, and as 1 inch deep and 2 inches broad,[4] and identical sets of experiments were made with the bar in both positions. Thus the behaviour of the outer fibre is observed when, though subjected to the same calculated stress, it is deflected through a different distance. Fine lines were drawn over the lateral surface of the beam perpendicular to its length, at a distance of 5 inches from each other, and the extensions of each 10-inch length were measured, the deflection at the middle of these 10-inch lengths being observed simultaneously. This was repeated with the beam in both positions on spans of 60 inches, 50 inches, 40 inches, and 30 inches. In order to determine the quantity analogous to the specific extension of the material, the Author caused the load of the machine to be transmitted simultaneously to two points, each 5 inches distant from the centre of the span. The effect of this is to produce a constant bending moment between the two points. The extensions of the outer fibre, between the two points of application of the load, were observed on a 60-inch 50-inch, and 40-inch span in both positions ▯ and ▭ and on a 30-inch span in this position ▭ only.

---

[1] The Author wishes to express his indebtedness to Professor A. B. W. Kennedy for his kindness in placing at his disposal for these experiments the new testing machine, specially designed by Professor Kennedy for experiments of this description.

[2] The cast dimensions were 63 inches by 3 inches by 1½ inch, a large amount being allowed for planing in order to ensure the thorough removal of the outer skin and any porous material.

[3] Minutes of Proceedings Inst. C E., vol. lxxxviii. p 30.

[4] The forces acting on the beam in the testing machines are vertical. For convenience, in future reference the following contractions will be used:— ▯ to denote the beam when tested as 2 inches deep, and ▭ to denote the beam when 1 inch deep, the depth being measured in the plane of the forces acting on the beam. Also as the bar was tested on several different spans, such a collection of symbols as this:—60 ▭ ↓ ↓ will mean that the conditions of testing were (i) a span of 60 inches; (ii) beam lying flatways; (iii) the load applied equally at two points symmetrically disposed about the centre of the span. Also the expression "double loading" will be synonymous with the conditions mentioned in (iii), and single loading will indicate that the load is applied at the centre of the span.

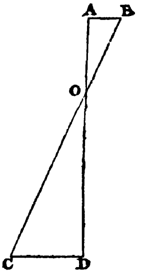
The method of conducting the experiment was as follows:—With double-loading, successive equal amounts were added, until a calculated stress of 20,000 lbs. per square inch was developed in the outer fibre. The load was then released and the set noted. Subsequent sets of readings were taken between the same limits until the extension at the time was elastic. Then other readings were taken from which the curves, Plate 5, Fig. 1, have been plotted. The same method was adopted on all spans both with double and single loading. When these series were complete, experiments on the extension of the outer fibres at high calculated stresses, up to 35,000 lbs. per square inch, were made to correspond with similar experiments in simple tension. Then the beam was broken on a span of 60 inches in this position ▭, and another series of experiments made in an exactly similar manner on the halves, one being eventually broken so ▭ and the other so ▯. Nearly 2,000 observations were made on this cast-iron bar alone, but only a summary of the figures is given in the Appendix, Table XVII. For the purpose of further information respecting the behaviour of the outer fibre in ductile material, the Author carried out some similar experiments on steel bars[1] of circular, rectangular, and double-tee cross section. For these experiments the Author designed the mechanism described in the Appendix.

The Author repeated Hodgkinson's experiment upon the diminution of the tensile modulus of elasticity of cast-iron as the stress increases, in order to obtain the amount of this diminution for the iron in question. The specimen (one of the three mentioned before, which were cast from the same ladle as the bar) was turned so as to remove the skin, and was frequently tested between the limits 0 and 16,000 lbs. per square inch by Professor Kennedy with the autographic-diagram apparatus, with a view to the measurement of the "time effect" on cast-iron. Subsequently, the Author continued the experiment with Professor Kennedy's lever-extension gear,[1] between the limits of stress 0 and 25,000 lbs. per square inch, the higher limit being within 500 lbs. per square inch of the breaking-stress of one of the other turned test-bars. When, after repeated testing between these limits (the usual phenomena pointed out by Bauschinger[2] obtaining) the extension became relatively wholly elastic, readings were carefully taken on both sides of the piece, the mean values of which are quoted in the Appendix.[3] To compare the behaviour of the iron in compression with this result, the Author prepared a cylinder, 4 inches long, and 1 inch in diameter,[4] which was subjected to a compressive-stress of 40,000 lbs. per square inch. The specific elastic compression remained fairly constant, that is, no distinct increase or decrease was manifested as the stress increased. Hence, if sections do remain plane after flexure, it follows that the position of the unstrained plane will be known if the intensity of stress on either side of the beam be known. For (Fig. 3) considering B C to be the position taken up by the A D after flexure relatively to its contiguous section,

---

[1] Dimensions in Appendix.

FIG. 3.



$$\frac{\text{O A}}{\text{O D}} = \frac{\text{A B}}{\text{C D}};$$

$$\therefore \frac{\text{O A}}{\text{A D}} = \frac{\text{A B}}{\text{A B} + \text{C D}}. \quad \text{A D} = \text{depth} = d.$$

A B here represents the degree of compression $= c$, C D the degree of extension $= e$. Thus the neutral axis is distant $d\,\frac{c}{c+e}$ from the compressed side, and $d\,\frac{e}{e+c}$ from the extended side.

In Plate 5, Fig. 1, are plotted all the elastic curves obtained from the extension of the outer fibre which are comparable with the tensile stress-strain curve. These curves are plotted to a horizontal axis of values of $\frac{M}{z}$, and it will be seen that the degree of coincidence with the tensile stress-strain curve varies. The curves which approximate most are 40 ▯ ↓ ↓ and 30 ▭ ↓ ↓, as far as a calculated stress of 20,000 lbs. per square inch, while the others have a less slope. It will be noticed that for the same span the curves agree fairly with each other for both positions (60 ▯ ↓ ↓ and ▭ and 50 ▯ ↓ ↓ and ▭). Curves 40 ↓ ↓ ▯ and ▭ are somewhat discrepant; 30 ▭ ↓ ↓ agrees fairly with 40 ▭ ↓ ↓, and consequently with the stress-strain curve. The extensions and deflections have been plotted, Plate 5, Fig. 2, of 60 ↓ ▭ and ▯, and 30 ↓ ▭ and ▯ as far as 32,000 lbs. per square inch;[1] 60 ↓ ▭ and both the curves on the 30-inch span are continued to rupture. Curve 30 ▭ ↓ rises rapidly and at rupture exhibits an extension on the outer fibre of 0·027 inch, which corresponds to a mean stress over the 10 inches of 11·4 tons per square inch. Curve 60 ▭ ↓ shows an extension at rupture of 0·033 inch; and 30 ▯ ↓ shows an extension of 0·0318 inch, corresponding respectively to mean stresses of about 13·5 and 13·2 tons per square inch.[2] Table V in the Appendix seems to show that the localization of stress under the load diminishes as the span decreases; thus it might be assumed in the 30-inch span that the stress is fairly evenly distributed to some little distance on each side of the section immediately under the load. But even were the stress to vary as the bending moment up to the centre of the span, the specific extension immediately under the load would be for the largest amount exhibited in the experiment, namely, 60 ▭ ↓, $0{\cdot}033 \times \frac{12}{11} =$ 0·0363 inch; whereas, if the stress-strain curve be continued, an extension of about 0·045 inch would correspond to a calculated stress of 36,000 lbs. per square inch.

---

[1] Minutes of Proceedings Inst. C E, vol. lxxxviii.

[2] Mittheilungen aus dem Mechanisch-technischen Laboratorium zu Munchen.

[3] For details see Appendix, Table I, Experiments A and B.

[4] *Ibid.*, Table I, Experiment D.

A number of experiments were made upon the amount of strain in the outer fibres under loads approaching the breaking-load. There being nothing remarkable about the results, except that they are analógous to the stress-strain curve of the material in pure tension, the figures will not be quoted. The results in the following Tables will be sufficient.

---

[1] These stresses are values of $\frac{M}{z}$ for the outer fibres in all cases.

[2] The value of $\frac{M}{z}$ at rupture is respectively 36,000, 36,000, and 35,500 lbs. per square inch.

A. SPAN = 60 INCHES. ↓

Load at Middle of Span	Stress $\left(=\frac{M}{z}\right)$	Extension on Middle 10-inch Length.	Deflection.
Lbs.	Lbs per Square Inch.	$\frac{1}{1000}$ Inch.	Inch.
0·00	..	0·00	0 00
755·48	34,000	31·17	1·85
799·98	36,000	33·53	1·97

The beam was tested in this position ▭. It held up for an instant at 36,000 lbs. per square inch on the outer fibre (calculated), then broke before readings could be taken. Those quoted are deduced from the behaviour of the beam during the experiments at high loads above-mentioned.

B SPAN = 30 INCHES ↓

RUPTURE OF ONE-HALF IN THIS POSITION ▭.

Load at Middle of Span.	Stress.	Extension on Middle 10-inch Length.	Deflection.
Lbs.	Lbs per Square Inch.	$\frac{1}{1000}$ Inch.	Inch.
0·00	..	0·00	0·00
888·88	20,000	15·41	0·30
1,065·65	24,000	19·53	0·37
1,244·42	28,000	23·05	0·43
1,333·30	30,000	25·40	0·45
1,422·18	32,000	27·41	0·48
1,511·06	34,000	29·53	0·50
1,599·94	36,000	31·99	0·53
0·00	0	4·23 set	0·05
1,599·94	36,000	27·06	0·58

The beam held up at 36,000 lbs. the second time just long enough to enable readings to be taken, rupture ensuing almost immediately.

C. SPAN = 30 INCHES. ↓

RUPTURE OF THE OTHER HALF IN THIS POSITION ▯.

Load at Middle of Span.	Stress.	Extension on Middle 10-inch Length.	Deflection.
Lbs.	Lbs per Square Inch.	$\frac{1}{1000}$ Inch.	Inch.
0·00	..	0·00	0·000
1,777·77	20,000	15·29	0·017
2,133·32	24,000	19·29	0·020
2,488·87	28,000	22·58	0·022
2,666·64	30,000	24 70	0·023
2,844·41	32,000	26·23	0·024
3,022 28	34,000	28 82	0·025
3,200·05	36,000	31·76	0·030

The beam held up at 36,000 lbs. per square inch just long enough to enable the readings to be taken.

The breaking loads of the remaining pieces of this beam on a span of 15 inches will be found in the Appendix, Table IV.

Of course, in experiments of this nature, it is impossible to arrive at the elastic extension at rupture.

In order to arrive at some definite conclusion as to the behaviour of the outer fibre in compression, and also to corroborate the results obtained with the very simple form of extensometer used in the experiments just described, the Author carried out a further set of experiments.[1] In these corroborative experiments on cast-iron the same delicate double extensometer was used as in the experiments on steel; only, owing to the nature of the extensometers, the observations could not be carried to so high a load as with the simple mechanism. The results, or rather as many of the results as affect the point under discussion, are plotted in Plate 5, Fig. 6. From these it is evident that the behaviour of the material is correctly interpreted by the formula $M = Sz$, even under a varying bending moment. From this it might be argued that the strain at rupture should correspond to the calculated stress. Practically, this is not the case; the reason for this, in the Author's opinion, is that the stress over the length upon which the strain was measured is differently distributed in different forms of cross section, being more or less evenly distributed as the form of the cross section is cruciform or double tee. The formula assumes that the intensity of stress varies directly as the bending moment, and therefore becomes a maximum immediately under the point at which the load is applied. It seems almost only common sense to assume that the degree in which this is true practically will be governed by the form of cross section, and that the real maximum stress in the beam will numerically fall short of the ratio of bending moment to the modulus of cross section, in the proportion that the stress conditions for some little distance on either side of the section on which the load is acting approach those of the beam when loaded, so as to cause a constant bending moment to obtain over the distance.

---

[1] See account of supplementary experiments on cast-iron in Appendix, on another machined cast-iron bar, which, together with three tensile test-pieces and one test-piece for compression, were specially prepared for these experiments after the experiments on steel (described later in the Paper) had been made. For these experiments the same testing machine was used as for the experiments on steel to be described later.

From this it is clear that the position of the neutral plane cannot be calculated at fracture unless the strain is actually measured; although, throughout the greater part of the life of the beam, the relation between the strain and the corresponding ratio of bending moment to the modulus of section is identical with that of the tensile stress-strain curve. Assuming that the real mean intensity of stress in the neighbourhood of the section immediately under the load is that corresponding to the same strain in the tensile stress-strain curve, the following positions of the neutral plane at rupture can be calculated for the three cases of rupture in the foregoing experiment.

For 60 ▭ ↓—

$$\frac{\text{extension at rupture}}{\text{extension at rupture} + (\text{specific compression} \times \text{stress corresponding to extension at rupture})}.$$

$$= \frac{0{\cdot}033}{0{\cdot}033 + 0{\cdot}00068 \times 30{,}500} = 0{\cdot}614 \text{ of depth of section.}$$

30 ▭ ↓ $\dfrac{0{\cdot}027}{0{\cdot}027 + 0{\cdot}00068 \times 25{,}500} = 0{\cdot}609.$

30 ▯ ↓ $\dfrac{0{\cdot}0318}{0{\cdot}0318 + 0{\cdot}00068 \times 29{,}600} = 0{\cdot}613.$

In order to investigate the ultimate effect of a load applied at two points in the span equidistant from the centre, the Author had twelve specimens cast in cast-iron, four of double-tee section, four of rectangular section, and four of circular section. Owing to unsoundness, those of circular section are valueless. The results yielded by the others, two of which in each case were tested with the single knife-edge, and two with the double knife-edge, were as follow:—

The beams were approximately 2 square inches in section.

Span.	Distance apart of the two Knife-edges in Double Loading.	Single or Double Loading.	Breaking Load per Square Inch.	Ultimate Deflection.	Section.
Inches.	Inches.		Lbs.	Inch	
36	13½	double	3,960	0·42	rectangular
”	”	double	4,020	0·45	”
”	”	single	2,765	0·37	”
”	”	single	2,500	0·30	”
”	”	double	6,800	0·19	joist
”	”	double	7,840	0·22	”
”	”	single	6,530	0·22	”
”	”	single	5,880	0·21	”

In the case of the double loading, a constant bending-moment exists between the two points at which the load is applied. Hence, theoretically, all slide in the section is got rid of; and it might be expected under these conditions, that the stress as measured by the ratio of bending moment to the modulus of cross section at rupture, and the ultimate tensile-stress of the material should coincide. That is (using ↓ to indicate single loading and ↓↓ double loading, and calling ratio of observed breaking-load to calculated breaking-load ϕ)—

$$\frac{\downarrow W\,36}{\downarrow\downarrow W\,22\tfrac{1}{2}} \text{ should } = \phi.$$

Now, in the case of the beams of double-tee section,

$$\text{the mean } \downarrow W \quad = \overset{\text{Lbs.}}{6{,}205};$$

$$\text{the mean } \downarrow\downarrow W = 7{,}320;$$

$$\text{and } \frac{6{,}205 \times 12}{7{,}320 \times 7\cdot 5} = 1\cdot 35, \text{ which is about the value of } \phi \text{ in this case.}$$

In the case of the rectangular beams,

$$\begin{array}{ll} & \text{Lbs.} \\ \text{the mean } \downarrow W & = 2{,}633\,; \\ \text{the mean } \downarrow \downarrow W & = 3{,}990\,; \\ \text{and } \dfrac{2{,}633 \times 12}{3{,}990 \times 7 \cdot 5} & = 1 \cdot 085, \end{array}$$

which is much under the value of ϕ for this case.

These results seem to point to the probability that the stress, as the piece approaches rupture, becomes distributed more evenly on each side of the section immediately under the load in the case of the beam of rectangular section than in the beam of double-tee section.

STEEL.

The specimens upon which the experiments were made were of Siemens Martin steel, containing 0·20 per cent. of carbon. They were three in number; one of circular section, one of rectangular section, and a 5-inch rolled steel joist. They were kindly supplied to the Author by Messrs. Dorman, Long and Co., of Middlesbrough, who also were good enough to arrange that all three were rolled from the same billet.[1] The beam of circular section was turned in order to remove scale; the beam of rectangular section was planed over the two sides on which extensions were to be measured, the other two sides were ground on a grindstone, and the top and bottom flanges and the edges of the flanges were planed. Test specimens for the determination of the tensile and compressive moduli, &c., were prepared from the ends of the rectangular bar and the rolled joist (Appendix, Table VII).

For the determination of the strains, a different measuring apparatus was employed in these experiments to that used in the first experiments on cast-iron. It is shown by Figs. 9, and an explanation of the constructive detail is given in the Appendix. The weight of the pointer acts with the spring M, not against it, when the gear is fixed to the centre of the span. In any position, however, the curvature due to the deflection within the limit of elasticity is so small that no appreciable error is introduced owing to the action of the weight of the pointer.

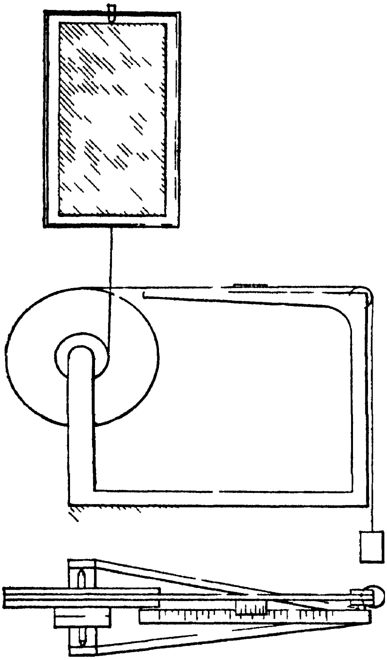
The vernier enables the position of the pointer on the scale to be

---

The dimensions of all these specimens are stated in the Appendix.

read accurately to 0·005 inch, and by estimation to 0·0005 inch, corresponding to a real movement of 0·000005 inch.

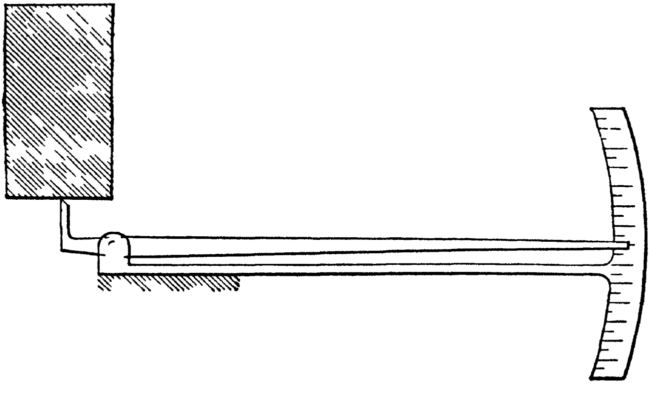
Figs 4



Some explanation is needed of the way in which the deflection of the beam at various points was measured. Of course, the type of testing-machine forms a very largely governing factor in the various devices adopted, so that a description of the machine would not be out of place; it is now, however, a well-known type.[1]

Two kinds of gear were adopted, one of the wheel-and-axle type (Figs. 4), and the other consisting of levers (Fig. 5). On an examination of the results, given by the first apparatus, discrepancies became apparent which could not be ascribed wholly to the much-abused "difference between theory and practice"—a difference, by the way, which engineers should aim at removing. Feeling sure that the anomalous results were due to strains in the testing-

Fig 5



---

[1] Institution of Mechanical Engineers. Proceedings, 1882, p 384

machine itself, the second gear was adopted, in which the centres, on which the pointers turn, are carried by a stiff piece of tee-iron, resting on the knife-edges by which the beam is supported, thus ensuring that only the relative motion of the beam to the straight line joining the upper edges of the supports shall be indicated by the pointers. This gear is of course not adapted for large deflections in the form in which it is shown in Fig. 5, but served its purpose very well for the measurement of elastic deflections of these bars. The results thus obtained are in striking accord with theory.[1]

This conflicts with the prevalent idea that the transverse modulus is smaller than that obtained from tensile-tests. But it is not unlikely that the discrepancy, so often noticed, is entirely due to careless or inaccurate testing. It is significant that experiments from the highest authorities never show this anomaly. It is evident that, in the case of large ratio of sectional area of the beam to span, the compression of the material over the supporting knife-edges will constitute a vitiating element in the observations if taken in the usual way, where the testing machine, on account of its size, is assumed to be rigid "for all practical purposes." The safest way of avoiding the disturbing tendency of strains in the machine itself is to decrease the ratio of sectional area to span, until the loads necessary to produce large deflections are tolerably small, when the compression of the material over the supports and the strains in the testing-machine itself become inappreciable.

Results of Experiments on Steel.

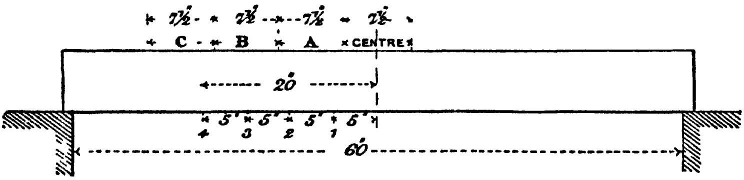
The field covered by the experiments and the quantities measured will best be seen by the accompanying diagram (Fig. 6) and Table. The capital letters denote the lengths over which strains were measured (on both sides of the beam). The figures denote the points at which the deflection was noted.

In every case, except when specially mentioned, both tensile and compressive-strains were measured simultaneously. The measurements were not taken on both sides of the beams as it was considered unnecessary,[1] although these would be undoubtedly useful as corroborative detail.

---

[1] The agreement of theory and practice in this case does not in any way prove that there is no slide in the section during elastic flexure, but shows that it is so small as to be inappreciable to the measuring instruments used by the Author. There can only be perfect accord between the results of $y = \frac{W}{E\,I}\left(\frac{l^2 x}{8} - \frac{x^3}{12}\right)$ and the observed deflection, in the case of material whose resistance to shear is infinitely great.

FIG. 6.



BEAM OF RECTANGULAR SECTION.

Strains.	Deflections[2] 2nd gear (lever type).
80 ↓ ↓ centre.	60 ↓ centre, 1, 2, 3.
80 ↓ A B C.	
60 ↓ ↓ centre.	

ROLLED JOIST.

Strains.	Deflections. 2nd gear.
60 ↓ ↓ centre.	60 ↓ centre. 1, 2, 3.
60 ↓ ↓ centre, 1 inch from centre line.	
80 ↓ ↓ " "	
80 ↓ centre.	
80 A.B C.	
80 ↓ extreme edge of compression flange. Compression only, space B.	
80 ↓ centre line compression only, measured on 70 inches.	
80 ↓ extreme outer edge, compression only, on 70 inches.	
60 ↓ centre.	

BEAM OF CIRCULAR SECTION.

Strains.	Deflections. 2nd gear.
60 ↓ ↓ centre.	60 ↓ centre, 1, 2, 3.
60 ↓ A′ B′.	

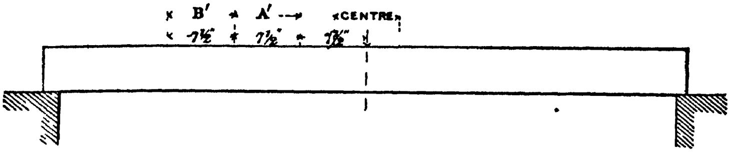
---

[1] Both sides of the beam were measured through one set of experiments, and the results yielded by each side were found to be identical.

[2] For reasons before mentioned the indications of the first gear have been rejected.

Owing to practical reasons, the strains were measured over lengths A′, B′, (Fig. 7) as shown in the case of the circular

FIG. 7.



beam, which are therefore distinguished as A′ B′. The deflections were measured at the same points as in the foregoing cases.

AFTER PASSING THE LIMIT OF ELASTICITY.

Strains only.

▯ 60 ↓ ↓ up to limit. Bar straightened, then 60 ↓ A.
▯ 60 ↓ ↓ centre, time effect at several loads.
I 60 ↓ ↓ up to limit.
60 ↓ ↓ centre, time effect at several loads.
○ 60 ↓ ↓ up to limit.
60 ↓ ↓ time effect at limit.

REMARKS ON THE RESULTS OF THE EXPERIMENTS ON STEEL.

The results, recorded in the "Summary of Results of Elastic Experiments on Steel Beams,"[1] show that within the limit of elasticity the ordinary theory of beams is correct, and that the ratio of the bending moment to the modulus of the section is, in the case of elastic material, a correct measure of the stress obtaining in the outer layers. The manner of applying the load makes no difference; nor is there any reason why it should. It is evident that the existence of "slide in the section," which the Author has shown to be visible by an experiment to be described later on,[2] can only affect the transverse modulus (calculated from deflections), and cannot disturb the strain conditions of the outer fibre.

In the summary above alluded to, the strains on the outer layers, which were measured on a length of 7½ inches, are reduced to specific strains, a quantity[3] introduced by Professor Kennedy.

---

[1] Appendix, Table VI.

[2] Appendix, p. 347.

[3] Institution of Mechanical Engineers. Proceedings, 1881, p. 205.

Through the kindness of Professor W. C. Unwin, the Author had an opportunity of testing one of the tensile-specimens, cut and turned from the rectangular beam, with a very delicate measuring apparatus, which has been described by Professor Unwin.[1] It is a trustworthy and useful extensometer, there being no back-lash, and the movement measured being the mean of two sides of the specimen. The Author tested the same specimen in tension and in compression with a lever extensometer, also giving the mean of both sides. But the results by the lever extensometer are not very satisfactory, owing, perhaps, to the want of skill on the part of the Author in using it. Those given by Professor Unwin's extensometer will therefore be accepted. The following Table shows the tensile modulus as calculated in three different ways:—

TENSILE MODULUS (LBS PER SQUARE INCH)

—	—	From Deflection of Beams.	From Strains of Beams	
			Tension	Compression.
From tensile-tests.	29,850,000	○ 31,150,000	30,000,000	30,100,000
From compressive-tests	29,800,000	I 29,450,000	29,500,000	30,200,000
		▯ 31,470,000	29,500,000	30,000,000

The modulus was also measured on the pieces cut from the flange and web of the rolled joist. As, however, these were not prepared, the results cannot be very trustworthy, and have not been introduced into the calculations.

With regard to the behaviour of ductile material as a beam within the elastic limit, it may be asked whether

(i.) The slide in the section within the elastic limit influences the distribution of strain in the outer fibre in any marked degree?

(ii.) Whether the form of cross section would also influence this appreciably?

(iii.) Whether the strain conditions at the limit of elasticity in a beam correspond to the strain conditions at the limit in tension?

(iv.) Whether the ordinary limit of elasticity (by deflection) of a beam obtains at that point at which the strain-meters indicate the limit in the outer fibre?

---

[1] Minutes of Proceedings Inst. C.E., vol. lxxxviii. p. 91.

It appears from an examination of the results that (i.) and (ii.) may be answered in the negative.

(iii.) Tables X, XII and XIV are corroborative of the opinions expressed in an earlier part of this Paper that the limit of elasticity cannot be so well defined a point in the load-deflection curve as in the load-strain curve. The beam of double-tee section exhibits the least unmistakable limit of elasticity, as shown by the strain-meters; the limit in the case of the rectangular bar is less well shown, and in the case of the beam of circular section it becomes quite indefinite. The following Table gives the stress in tons per square inch at which the limit of elasticity was reached in the beams, as indicated by the strain-meters and in the test-pieces.

Test-pieces.		Beams.[1]			
		From Strain-meters.		From Autographic Load Deflection Diagram.	
No. 1 . .	17·65	▯ 60 ↓↓	18·05	▯ 41 ↓	20·45
„ 2 . .	17·36	○ 60 ↓↓	17·06	○ 41 ↓	25·68
„ 3 . .	18·49	I 60 ↓↓	17·53	I 41 ↓	23·66
„ 4 . .	17·28				
Mean . .	17·70	17·55		23·26	

The permanent strains of the outer fibre when the maximum load was reached were measured on the rectangular and circular bars.

Owing to the joist buckling, at the flange and in the web, the maximum load which such a bar would resist was never reached. Although the strain at the centre of the span is greater in the circular than in the rectangular bar, when they had both been bent as far as possible, the latter had bent to a considerably sharper angle, thus lending a degree of probability to the opinion that the material near the centre of gravity of the section, however inefficient in resisting elastic flexure, forms a large factor in the ultimate strength of the beam.

---

[1] Unfortunately the deflections of the beams at the limit of elasticity on a span of 60 inches with double loading were not satisfactorily measured. The indications of the autographic load deflection diagrams, though inserted, are, therefore, not strictly comparable.

The resistance of a beam when the maximum load is reached is apparently conditioned by the following considerations:—

(i.) From an inspection of the magnitude of the strains, and from a comparison with the stress-strain curve of the material in tension and in compression, it is seen that, at the point in question, the whole section except a zone of small breadth near the neutral axis is in a state of more or less complete plasticity.

(ii.) The value of this zone of semi-elastic and completely elastic material, as a source of resistance, varies with the mass of metal included in it.

(iii.) Owing to the nature of ductile material, the most strained section must have appreciably altered its shape (though not necessarily its size) when the maximum load is reached. The outer layers in tension become attenuated, those in compression become engrossed.

(iv.) The maximum tensile-stress endured is therefore enhanced, and the maximum compressive stress is diminished.

(v.) The position of the unstrained layer is changed, and moves towards the compression side as flexure proceeds universally.

(vi.) Permanent deformation by shear occurs in several planes.

It is evident that a formula which would faithfully represent all the foregoing conditions, would be of considerable complexity. The refinement in accuracy thus introduced would probably not be so great as to counterbalance the inconvenience attending the use of a formula involving so careful an observation of many points in the life of a tensile-test specimen otherwise of no use in general practice.

It is certain that the maximum load cannot be reached before the outer layers become plastic,[1] and it is equally certain that the maximum load will not be reached before the outer layer has reached its limit of plasticity. Stricture must have actually commenced in the outer layer before the maximum load is reached. The exact point at which the maximum resistance is offered will vary, of course, with every material.

For practical purposes, as an amendment to the present empirical formula, the following suggestion might be found useful, namely, that in order to find the maximum load a beam will bear, the value of S in the formula

---

[1] This is easily shown thus:—

Let a portion x of the depth be plastic, then the rest $\frac{d}{2} - x$ is elastic. The moment of resistance of the plastic portion is $2\left(b\,x \times \mathrm{S}p \times \frac{d}{2} - \frac{x}{2}\right)$, and of the elastic portion $= \frac{b\,(d - 2\,x)^2}{6} \times \mathrm{S}\,p$, where $\mathrm{S}\,p =$ the stress at which plasticity obtains.

$$W = \frac{4\,S\,Z}{L}$$

should be the real stress at the limit of plasticity, and not the nominal breaking tensile stress of the material in question.

When the experiments on the elastic behaviour of the beams were concluded, the bars were all subjected to a load sufficient to cause them to reach the limit of elasticity. The loads were applied by the double knife-edge. After the limit was passed some experiments on the time-effect of high loads were made. This is an important and wide field for experimental research; the results obtained here can only be looked upon as purely tentative. After this the beams were bent as far as possible on a span of 41 inches, an autographic load-deflection diagram being taken of each. The results of the time-effect experiments are interesting, as bearing on the subject of the ultimate value of the material when distributed throughout the section in so totally differing ways as the three sections under consideration.

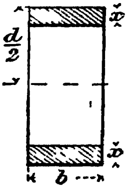
In the Appendix[1] will be found the results of these experiments. The vertical scale is the total increase of tensile and compressive strain, the horizontal scale is time in seconds, the load remaining the same during each experiment. The crosses and circles indicate points observed. From these results the equation to the curve has been determined. They are all of the same form—

$$\text{strain} = A - \frac{B}{(\text{Time}) + C},$$

where A B and C are constants whose value is different in each case.

Moment of resistance of section when wholly elastic = $S\,p\,\frac{b\,d^2}{6}$. Now $\frac{b\,d^2}{6}$ cannot be equal to $\frac{b}{6}\,(d - 2\,x)^2 + b\,x\,(d - x)$ unless $x = 0$.

FIG. 8.



If $$\frac{b\,d^2}{6} \text{ is} > \frac{b}{6}\,(d - 2\,x)^2 + b\,x\,(d - x)$$

then $$1 \text{ is} > \frac{1}{d^2}\,(d^2 - 4\,d\,x + 4\,x^2) + \frac{6}{d^2}\,(d\,x - x^2)$$

$$1 \text{ is} > 1 + \frac{2\,x}{d} - \frac{2\,x^2}{d^2},$$

in order that this may be true

$$\frac{2\,x^2}{d^2} \text{ must be} > \frac{2\,x}{d}, \text{ which is impossible;}$$

hence $$\frac{b\,d^2}{6} \text{ is} < \frac{b}{6}\,(d - 2x)^2 + b\,x\,(d - x).$$

[1] Appendix, Tables XV and XVI, and Plate 5, Fig 4.

It will be noticed that though the curves are similar in form, the difference in the value of the constants is enormous. When the breakdown point is reached in the rolled joist, the support given by the still elastically acting inner portion is not much; while, in the rectangular section, it is comparatively considerable. It might thus be expected that the time-effect would increase in rapidity in bars of rectangular section, owing to more of the section becoming plastic; while double tees might be expected to act differently, and that the beam of circular section would more rapidly take up a position of equilibrium under a given load, owing to the increasing width of the cross-section from the outer layer inwards.

NOTES AS TO THE EXPERIMENTS.

The distance between the points to which the load is transmitted by the double knife-edge is 10 inches in the case of the first experiment on a cast-iron bar (alluded to on p. 315); but in the supplementary experiments on cast-iron, and in all the experiments on steel, this distance was 13½ inches. The length over which strains were measured was, in the first instance, 10 inches, in the second, 7½ inches. In all the Tables relating to flexure, the figures in the column headed "stress per square inch" are obtained from the formula $S = \frac{M}{Z}$.

It is perhaps unnecessary to draw attention to the points of minor interest in the results of the experiments, as these will be obvious on an inspection of the Tables, which the Author ventures to hope are sufficiently explicit.

The Paper is accompanied by a number of diagrams from which Plate 5 and the Figs. in the text have been engraved.

APPENDIX.

Testing-Machines.

The testing-machines used were (i) a 50-ton Wicksteed,[1] (ii) a 50-ton Greenwood and Batley, (iii) a testing-machine specially designed by Professor Kennedy for transverse-tests. The load is applied by a hydraulic ram moving a cross-head guided by slipper-guides on the main casting. For tensile-tests the specimen is fixed by taper wedges between this cross-head and a shackle attached to the scale-beam, along which a weight of 1 ton can be rolled, thus supplying a means of measuring the pull on the specimen. For compression or bending, a strong, heavy cross-piece, also guided on the main casting, is slung by four ties from the upper shackle, the cross-head of the ram being between the upper shackle and the cross-piece. The piece to be compressed, or bent, is arranged between the ram cross-head and this cross-piece; thus the load on the piece is transmitted by means of the ties to the scale-beam, and is measured in the ordinary way. For all practical purposes the friction in these guides may be neglected. When, however, a long strut is being tested, unless everything is "dead" in line, the friction in the guides becomes appreciable.

All the knife-edges are blunt, but where heavy loads were to be applied, rollers were substituted in the supports. These rollers could only revolve about their axis, the distance between their axis remaining fixed.

Measuring-Apparatus.

For the measurement of strains within the elastic limit of the beams, the mechanism shown by Figs. 9 was designed by the Author. It consists of a lever P, the lengths of whose arms are as 100 to 1, the fulcrum being carried by the main casting, which, when in position on the beam, becomes rigidly connected to the beam. A piece of uncoiled watch-spring W, of any length in this case, of such a length as to allow of the main screws T_1 T_1 being placed 7½ inches apart, is pivoted to the small arm of the lever P by means of the saddle S, and to the other fixed point of the gear G by the sliding piece L, serves to cause the motion of the pointer when the distance between the main screws T_1 T_1 is in any way changed. The saddle S is attached to a spring M by a silk thread. By means of the fore and back nuts N_1 N_1 and the sliding-piece L the position of the pointer on the scale can be adjusted as required. The main screws T T admit of the position of the watch-spring on the surface of the beam being adjusted. The screws *m* allow for another adjustment, which was often found to be necessary owing to the centre punch marks in which the screws T T rest not being exactly opposite each other on both sides of the beam. On the compression side, the watch-spring was constrained to follow

Institution of Mechanical Engineers. Proceedings, 1882, p. 384.

the curve of the beam by means of an arrangement resembling a light ladder, which was itself loaded with little bags of shot. All rotating parts move on accurately made steel centres working in carefully drilled and slightly countersunk holes. The apparatus for measuring the deflection has been already sufficiently described (Figs 4 and 5 in the text). An autographic load deflection diagram was taken of all the pieces when loaded beyond the elastic limit.

Plate 5, Fig 1, shows the values of the strains under the double knife-edge on the 63 inches by 2 inches by 1 inch cast-iron bar for various spans.

Plate 5, Fig. 2, gives the extensions of the centre 10-inch length of the same bar for various spans when the load is applied at the middle of the span (single knife-edge), and the corresponding deflections at the middle of the span in a similar way. It is interesting to note that at the same calculated stress the strain on the outer fibre is very nearly the same, although the deflection varies so much.

Plate 5, Fig 3, shows the amount of extension and compression respectively endured over a length of 7½ inches at the middle of the span at a space A, and the deflection at the middle of the span, the load being applied at that point. The non-coincidence of the limit of elasticity, as shown by the strain-meters and the deflection, is interesting.

Figs 9.

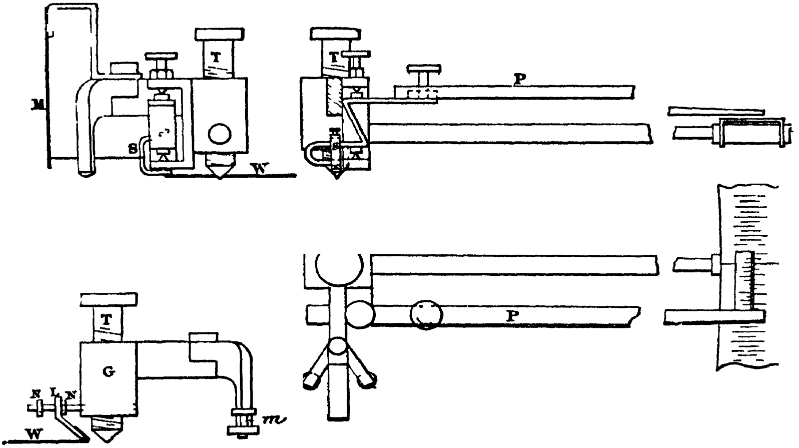


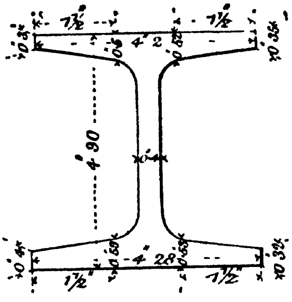
Plate 5, Fig 4, shows the relative effect of a load without the limit of elasticity on beams of different sections. The vertical and horizontal scales are the same for each curve. The enormous difference of effect in the cases of the girder section and the rectangular section of a load, at a similar epoch in the life of the beam, is a further proof of the real ultimate value of metal disposed in the neighbourhood of the centre of gravity of the section. The horizontal axis indicates the origin for increase of strain due to an additional load Thus curves C and D are the strains caused by the additional ½ ton, and should be added to the strains already caused by the existing load before the ½ ton was added, which are shown by the curves A and B.

Finished Dimensions of Steel Specimens.

Beams.

Form of Section.	Dimensions.	Remarks.
▯	3·03 inches by 1·7 inch by 8 feet long. . . .	Sides *aa* planed. „ *bb* ground.
○	3·22 inches in diameter by 5 feet 3 inches long. . . .	Turned over whole length.
I	See Fig. 10 . .	Both flanges and their edges planed.

Fig. 10.



Test-pieces.

Nos. 1 and 2. Cut from the end of the rectangular beam and turned, 1·143 inch in diameter, screwed at both ends, 1⅜ inch in diameter.

No. 3 Cut from web of double tee and milled, area of cross section 2·0 inches by 0·39 inch = 0·782 square inch.

No. 4. Cut from flange of double tee and milled, area of cross section 1·421 inch by 0·493 inch = 0·7 square inch.

Table I.—Tension. Experiment A.

November 9th, 1886.

Particulars of experiment: Tensile-test of a piece of the same cast iron as the bar, 63 inches long by 2 inches by 1 inch before referred to. Turned. Dimensions of specimen, 0·911 inch in diameter; area, 0·625 square inch. Extensions measured on 10 inches.

Total Load.	Stress in lbs. per Square Inch.	Extensions, 1,000ths of an Inch.	
		Scale Reading.	Sum of Differences.
Lbs.	Lbs.		
0	0	7·04	..
15,625	25,000	9·83	2·79
0	0	7·25	set = 0·21
15,625	25,000	9·99	2·74
0	0	7·38	set = 0·13
15,625	25,000	9·96	2·58
0	0	7·40	set = 0·02
15,625	25,000	9·96	2·56
0	0	7·42	set = 0·02
12,500	20,000	9·40	1·98
15,625	25,000	10·00	2·58
0	0	7·45	set = 0·03
15,625	25,000	10·00	2·55
0	0	7·45	set = 0·0

In all the tests recorded in Table I, the specimen was held in the way described by Professor Kennedy in his Paper on "The Use and Equipment of Engineering Laboratories," Minutes of Proceedings Inst. C.E., vol. lxxxviii.

Breaking-stress of this material 11·6 tons per square inch.

TABLE I.—*continued.* TENSION. EXPERIMENT B.

PLATE 5. FIG. 5. CURVE A.

November 9th, 1886.

Particulars of experiment: Cast-iron test-piece as before. Dimensions of specimen, 0·911 inch in diameter; area, 0·625 square inch. Extensions measured on 10 inches.

Stress per Square Inch.	One Side, 100ths of an Inch.		Other Side, 1,000ths of an Inch.		Mean, 1,000ths of an Inch
	Scale Reading.	Differences.	Scale Reading.	Differences.	Sum of Differences
Lbs.					
0	0·000	.	0·00	..	..
4,000	0·330	0·330	0·29	0·29	0·310
6,000	0·500	0·170	0·48	0·19	0·490
8,000	0·680	0·180	0·67	0·19	0·675
10,000	0·880	0·200	0·87	0·20	0·875
12,000	1·080	0·200	1·08	0·21	1·080
14,000	1·285	0·205	1·30	0·22	1·293
16,000	1·495	0·210	1·51	0·21	1·503
18,000	1·710	0·215	1·74	0·23	1·725
20,000	1·945	0·235	1·98	0·24	1·962
22,000	2·180	0·235	2·23	0·25	2·205
24,000	2·440	0·260	2·48	0·25	2·460
25,000	2·570	0·130	2·67	0·15	2·600
0	no set	..	no set	no set	..

TABLE I—*continued*. TENSION. EXPERIMENT C.

PLATE 5. FIG. 5. CURVE B.

January 28*th*, 1888.

Particulars of experiment: Cast-iron test-piece (same as was tested on 9th November, 1886), re-tested for determination of effect of time on range of elastic extension. Professor Kennedy's new extension gear used, which gives the mean of both sides. Broke at exactly 25,000 lbs per square inch. Dimensions of specimen, 0·911 inch in diameter; area, 0·652 square inch. Extensions measured on 10 inches.

Total Load.	Stress per Square Inch.	Extensions, 100ths of an Inch.	
		Scale Reading.	Set.
Lbs. 0	Lbs. 0	0	0
1,250	2,000	1·40	0·00
2,500	4,000	3·19	0·00
3,750	6,000	5·25	0·15
5,000	8,000	7·35	0·20
6,250	10,000	9·50	0·25
7,500	12,000	11·55	0·52
8,750	14,000	13·90	0·65
10,000	16,000	16·20	1·00
11,250	18,000	18·56	1 30
12,500	20,000	21·24	1·44
13,750	22,000	23·90	1·70
15,000	24,000	27·15	2·15
15,625	25,000	broke unexpectedly	

COMPRESSION. EXPERIMENT D.

Particulars of experiment: Specimen for compression. Square ends. Test for degree of constancy of E_c within extreme limit of nominal tensile-stress $\left(\frac{M}{Z}\right)$ in a cast-iron beam at rupture. On being first subjected to load of 14,400 lbs. a large permanent set was observed. Dimensions of specimen, 4·25 inches long; 0·97 inch in diameter; area, 0·74 square inch. Extensions measured on 3½ inches.

Total Load.	Stress per Square Inch.	One Side Compression, 100ths of an Inch. Scale Reading.	Other Side Compression, 100ths of an Inch. Scale Reading.	Mean of both Sides, 100ths of an Inch. Sum of Differences.
Lbs.	Lbs.			
5,920	8,000	0·000	0·000	0·0000
8,880	12,000	0·065	0·070	0·0675
9,360	14,000	0·110	0·120	0·1150
11,840	16,000	0·140	0·160	0·1500
13,320	18,000	0·170	0·210	0·1900
14,800	20,000	0·210	0·250	0·2300
16,280	22,000	0·260	0·290	0·2750
17,760	24,000	0·300	0·330	0·3150
19,240	26,000	0·330	0·365	0·3475
20,720	28,000	0·380	0·410	0·3950
22,200	30,000	0·420	0·450	0·4350
23,680	32,000	0·455	0·490	0·4725
25,160	34,000	0·500	0·530	0·5150
26,640	36,000	0·535	0·560	0·5475
28,120	38,000	0·580	0·600	0·5900
29,600	40,000	0·620	0·650	0·6350
5,920	8,000	0·010	0·020	..

TABLE II.

Measurement of variation of strains in the flange of the beam of double-tee section. Strains on centre line and on outer edge, 2 inches from the centre line. Compression only. (Simultaneous measurements of extension and compression were made, but the differences were so minute as to be hardly perceptible on 7½ inches) Strains measured on 70 inches; span, 80 inches; single knife-edge.

Load.	Strain, 1,000ths of an Inch. On Centre Line, A.	Strain, 1,000ths of an Inch. On Outer Edge, B.	A – B.	$\frac{A - B}{A}$.
Tons.				
0	0·000	0·000	0·000	0·0000
1	0·640	0·595	0·045	0·0703
2	1·315	1·230	0·085	0·0646
3	1·980	1·870	0·110	0·0555

TABLE III.—OBSERVED and CALCULATED EXTENSION of OUTER FIBRE.[1]

Calculated extension $= C \sqrt{W \delta}$.

Assumed observed extension throughout the whole span:—

For 60-inch span $=$ centre $+ 2\,B + 2\,D + \frac{1}{2}\,D$.
For 50-inch span $=$ centre $+ 2\,B + C$.
For 40-inch span $=$ centre $+ 2\,B + \frac{1}{2}\,B$.

(See Fig. 11, Table XVII, for meaning of A, B, C, &c.)

Load = 356 lbs. at centre of span on ▯
178 „ „ „ ▭
corresponding to value of $\frac{M}{Z} = 8{,}000$ lbs. per square inch.

Description.	Formula.	Observed.
60 ▭ ↓	0·01950	0·01813
60 ▯ ↓	0·02059	0·01850
50 ▭ ↓	0·01354	0·01230
50 ▯ ↓	0·01303	0·01260
40 ▭ ↓	0·00836	0·00905
40 ▯ ↓	0·00921	0·00920

Load = 800·64 lbs. at centre of span on ▯
400·32 „ „ „ ▭
corresponding to $\frac{M}{z} = 18{,}000$ lbs. per square inch.

Description.	Formula.	Observed.
60 ▭ ↓	0·0440	0·0385
60 ▯ ↓	0·0465	0·0382
50 ▭ ↓	0·0301	0·0268
50 ▯ ↓	0·0312	0·0277
40 ▭ ↓	0·0191	0·0184
40 ▯ ↓	0·0207	0·0168

---

[1] The values of the total extension derived from the formula, and from observation, agree better at a low than at a high load. This seems to indicate that, provided, of course, no error in experimental observation exists, as the load on the beam increases, the deflection becomes greater than it should do theoretically, which is what might be expected, owing to the slide in the section being considerable on account of the low shearing-stress of cast-iron.

TABLE IV.—BREAKING-LOADS of PIECES of BEAM on a SPAN of 15 INCHES.

(Carried out in the Greenwood and Batley Testing Machine.)

Two pieces tested in this position ▭.

	Lbs.
Breaking-loads	3,580 3,300
Mean	3,440
Mean breaking-stress	38,000 per square inch.
	Inch.
Deflection	0·190 0·160
Mean	0·175

Two pieces broken in this position ▯.

	Lbs.
Breaking-loads	6,950 6,520
Mean	6,735
Mean breaking-stress	37,200 per square inch.
	Inch.
Deflection	0·0950 0·1000
Mean	0·0975

TABLE V.—CAST-IRON BEAM.

If $M = S z$, the extensions on the lengths marked A, B, C, D, should vary directly as the mean bending moment over the length. Thus for a given load:—

$$\text{Ext. D} \times \tfrac{5}{2} \text{ should} = \text{Ext. C} \times \tfrac{5}{3} = \text{Ext. B} \times \tfrac{5}{4} = \text{Ext. A.}$$

EXTENSIONS.

—	60-inch Span ↓.		50-inch Span ↓.		40-inch Span ↓.	
	▯	▭	▯	▭	▯	▭
A	3·625	4·050	3·70	3·37	2·37	2·37
$B \times \frac{5}{4}$	3·810	3·600	3·23	3·00	2·35	2·50
$C \times \frac{5}{3}$	3·500	3·250	2·45	3·10		
$D \times \frac{5}{2}$	3·120	3·187				

The modulus used in these calculations is not the instantaneous modulus at the stress due to the given load at the centre. If the instantaneous modulus were introduced, it would tend to slightly aggravate the discrepancy between the observed and the theoretical results, since by the formula the extension varies inversely as the square root of the modulus.

TABLE VI.—SUMMARY of RESULTS of ELASTIC EXPERIMENTS ON STEEL BEAMS.

—			Steel.		Steel.		I Steel.	
Form of section			▯		○		I	
Area of section, square inches			5·15		8·14		5·30	
Modulus of section (Z)			2·603		3·273		9·05	
Span, inches			60	80	60	80	60	80
Mean strains on 10 inches for calculated stress of 1,000 lbs. per square inch on outer fibre, in 1,000ths of an inch, deduced from actual measurements on 7½ inches.	Tension.	Centre ↓ ↓	0·3150	0·336	0·332	..	0·3270	0·338
		A ↓	..	0·343	A′ 0·337	..	..	0·341
		B ↓	..	0·331	B′ 0·329	..	..	0·338
		C ↓	..	0·339	..	..	..	0·338
	Compression.	Centre ↓ ↓	0·3250	0·333	0·325	..	0·3330	0·325
		A ↓	..	0·333	A′ 0·332	..	..	0·307
		B ↓	..	0·335	B′ 0·337	..	..	0·335
		C ↓	..	0·331	..	..	..	0·338
Mean deflections for load of 1 ton on the beam, in inches.	Observed (with lever gear).	Centre ↓	0·0815	..	0·0613	..	0·0161	..
		1 ↓	0·0787	..	0·0598	..	0·0155	..
		2 ↓	0·0700	..	0·0534	..	0·0135	..
		3 ↓	0·0562	..	0·0450	..	0·0109	..
		4 ↓						
	Calculated, taking E from results of tensile test-pieces.	Centre ↓	0·0824	..	0·0616	..	0·1530	..
		1 ↓	0·0792	..	0·0592	..	0·1470	..
		2 ↓	0·0702	..	0·0525	..	0·1300	..
		3 ↓	0·0567	..	0·0423	..	0·1080	..
		4 ↓						
Maximum load (tons) Span = 41 inches			11·00		14·22		25·31	

TABLE VII.—RESULTS of STEEL TEST-PIECES.

——	No. 1.	No. 2.	No. 3.	No. 4.
Sectional area . . . . square inch	1·0264	1·0264	0·783	0·700
Strains measured on 10 inches at mean stress of 1,000 lbs per square inch . 1,000ths of an inch tension	0 335	0·322	0·315	0·324
compression	0·336			
Limit of elasticity, load . . . tons	18·12	17·82	14·47	12·10
„ „ stress tons per square inch	17·65	17·36	18·49	17·28
Maximum load . . . . . tons	28·34	28·42	23·41	20·33
„ stress . tons per square inch	27·70	27·75	29·90	29·04
Extension on 10 inches at limit of elasticity . . . . per cent	19·75	20·00	20·00	21·03
Total extension of 10-inch . . „	27·20	23·75	..	..
Mean extension apart from stricture . . . . . . „	..	19·20	..	..
Area at fracture . . . square inch	0·444	0·450	..	..
Real stress at fracture . tons per square inch	..	..	.	..
Reduction of area . . . . per cent.	56·7	56·1	..	..

TABLE VIII.

May 4th, 1888.

Particulars of experiment: Determination of specific extension and compression, rectangular section; deflection measured simultaneously. Dimensions of specimen 3·031 inches by 1·700 inch; area, 5·15 square inches; Z = 2·603; span, 60 inches, double knife-edge. Extensions measured on 7½ inches.

Total Load.	Stress per Square Inch.	Extension.		Compression		Deflection.	
		Position Centre.					
		100ths of an Inch.		100ths of an Inch.		5ths of an Inch.	
		Scale Reading.	Differences.	Scale Reading.	Differences	Scale Reading.	Differences.
Tons.	Lbs.						
0	..	0·000	..	0·000	..	0·00	..
¼	2,528	0·060	0·060	0·055	0 055	0·11	0·11
½	5,055	0·125	0·065	0·115	0·060	0·21	0·10
¾	7,583	0·190	0·065	0·175	0·060	(0·26?)	..
1	10,110	0·255	0·065	0·235	0·060	0·41	..
1¼	12,638	0·320	0·065	0·300	0 065	0·51	0·10
1½	15,165	0·380	0·060	0·360	0 060	0·61	0·10
1¾	17,693	0·445	0·065	0·425	0·065	0·71	0·10
2	20,220	0·510	0·065	0·490	0·065	0·81	0·10

TABLE IX.

May 4th, 1888.

Particulars of experiment: Strains measured at centre position; rectangular section; span increased to 80 inches. Dimensions of specimen in Appendix; area, 5·15 square inches; $Z = 2 \cdot 603$; span, 80 inches; double knife-edge. Extensions measured on 7½ inches.

Total Load.	Stress per Square Inch.	Extension, 100ths of an Inch.		Compression, 100ths of an Inch.		Deflection, Inches.	
		Scale Reading.	Differences.	Scale Reading.	Differences.	Scale Reading.	Differences.
Lbs.	Lbs.						
0	0	0·000	..	0·000	.	0·000	..
¼	3,603	0·070	0·070	0·085	0·085	0·046	0·046
½	7,206	0·160	0·090	0·170	0·085	0·096	0·050
¾	10,809	0·250	0·090	0·260	0·090	0·144	0·048
1	14,410	0·345	0·095	0·350	0·090	0·194	0·050
1¼	18,013	0·430	0·085	0·445	0·095	0·244	0·050
0	0	0·000	..	0·000	..	0·000	..

TABLE X.

June 1st, 1888.

Particulars of experiment: Beam of rectangular section loaded up to limit of elasticity. Strains measured at centre position. Dimensions of specimen in Appendix; area, 5·15 square inches; $Z = 2 \cdot 603$; span, 60 inches; double knife-edge. Extensions measured on 7½ inches.

Total Load.	Stress per Square Inch.	Extension, 100ths of an Inch.		Compression, 100ths of an Inch	
		Scale Reading.	Differences.	Scale Reading.	Differences.
Tons.	Tons.				
0	0·00	0·0000	..	0·0000	..
3¾	16·93	0·9050	0·9050	0·9410	0·9410
0	..	no set	..	no set	..
4	18·05	0·9900	0·0850	1·0240	0·0830
0	..	0·0250	..	0·0300	..
4¼	19·18	1·1300	0·1400	1·1410	0·1170
0	..	0·0800	..	0·0920	..
4½	20·31	1·3200	0·1900	1·3410	0·2000
1 min.	..	1·3450	0·0250	1·3640	0·0230
2 min.	..	1·3550	0·0100	1·3710	0·0070
3 min.	..	1·3600	0·0050	1·3760	0·0050
4 min.	..	1·3625	0·0025	1·3785	0·0025
5 min.	..	1·3700	0·0075	1·3850	0·0075
6 min.	..	at rest	..	at rest	..
0	0·00	0·2400	..	0·2920	..

Table XIII.

May 7th, 1888.

Particulars of experiment: Determination of specific extension and compression. Beam of double-tee section. Deflection measured simultaneously. Dimensions of specimen in Appendix. Area, 5·3 square inches; Z = 9·05; span, 60 inches; double knife-edge. Extensions measured on 7½ inches.

Total Load.	Stress per Square Inch.	Extensions, 100ths of an Inch.		Compression, 100ths of an Inch		Deflection, 5ths of an Inch.	
		Scale Reading	Differences.	Scale Reading.	Differences.	Scale Reading.	Differences.
Lbs.	Lbs.						
0	..	0·000	..	0·000	..	0·000	..
¼	0·32	0·010	0·01	0·015	0·015	0·025	0·025
0	..	0·005	..	0·005	..	0·005	..
½	0·65	0·025	0·015	0·035	0·020	0·045	0·020
0	..	0·005	..	0·005	..	0·005	..
¾	0·97	0·045	0·020	0·050	0·015	0·075	0·030
0	..	0·005	..	0·005	..	0·005	..
1	1·30	0·060	0·015	0·070	0·020	0·095	0·020
0	..	0·005	..	0·005	..	0·005	..
1¼	1·62	0·075	0·015	0·090	0·020	0·115	0·020
0	..	0·005	..	0·005	..	0·005	..
1½	1·95	0·095	0·020	0·105	0·015	0·135	0·020
0	..	0·005	..	0·005	..	0·005	..
1¾	2·27	0·110	0·015	0·125	0·020	0·165	0·030
0	..	0·005	..	0·005	..	0·005	..
2	2·60	0·125	0·015	0·145	0·020	0·185	0·020
0	..	0·010	..	0·005	..	0·005	..
2½	3·25	0·160	0·035	0·180	0·035	0·235	0·050
0	..	0·010	..	0·005	..	0·005	..
3	3·89	0·195	0·035	0·215	0·035	0·275	0·040
0	..	0·010	..	0·005	..	0·005	..
3½	4·54	0·230	0·035	0·250	0·035	0·325	0·050
6	7·79	0·410	..	0·435	..	0·565	..
0	..	0·010	..	0·005	..	0·015	..
6½	8·44	0·440	0·030	0·470	0·035	0·605	0·040
0	..	0·010	..	0·005	..	0·015	..
7	9·09	0·480	0·040	0·505	0·035	0·655	0·050
0	..	0·010	..	0·005	..	0·015	..

TABLE XIV.—TENSION. COMPRESSION. FLEXURE.

June 7th, 1888.

Particulars of experiment: Beam of double-tee section loaded until limit of elasticity reached. Dimensions of specimen in Appendix. Area, 5·3 square inches; $Z = 9 \cdot 05$; span, 60 inches; double knife-edge. Extensions measured on 7½ inches.

Total Load.	Stress per Square Inch.	Extension, 100ths of an Inch.		Compression, 100ths of an Inch.	
		Scale Reading.	Differences.	Scale Reading.	Differences.
Tons.	Tons				
0	..	0·000	..	0·000	
12	15·58	1·083	..	0·980	
0	..	0·218	..	0·110	
12	15·58	1·093	..	1·000	
12½	16·23	1·163	..	1·055	
13½	17·53	[a]			
..	..	1·568	..	1·415	
1 min.	..	1·698	0·130	1·540	0·125
2	..	1·768	0 070	1·605	0·065
3	..	1·833	0·065	1·668	0·063
4	..	1·878	0·045	1·715	0·047
5	..	1·913	0·035	1·765	0·050
6	..	1·950	0·037	1·798	0·033
7	..	1·978	0·028	1·817	0·019
8	..	2·010	0·032	1·850	0·033
9	..	2·033	0·023	1·870	0·020
10	..	2·055	0·022	1·890	0·020

Experiment to Determine in how far originally Plane Sections, Perpendicular to the Axis of a Beam, remain Plane after Flexure in the case of such Material as Lead.

The Author obtained a lead casting, which, after machining, was 38 inches by 7·7 inches by 2·1 inches. One side and one edge were planed. Lines were drawn at a distance of 1 inch apart parallel to the direction of the application of the load. The casting was tested as a beam on a 32-inch span, being supported on plates and rollers, and similar precautions were taken to prevent the centre knife-edge from sinking into the metal. The distance between the axes of the rollers was fixed and did not alter. The maximum load borne was 8 tons. The experiment was stopped when the tension side of the beam began to show signs of breaking, but it was then too late, and the lines which before had become S-shaped near the centre of the span were spoilt, and it was impossible to reproduce them.

---

[a] When the load was increased to 13½ tons, the pointer moved so rapidly over the scale that it was impossible to take a reading until it had nearly come to rest, when the next reading, viz. 1·568, was observed.

TABLE XV.—TIME-EFFECT.

Load, 5 tons at the centre.

Conditions, ▯ 60 ↓↓. Strains measured on 7½ inches.

Time.	Tension, 100ths of an Inch.	Compression, 100ths of an Inch.	Time.	Tension, 100ths of an Inch.	Compression, 100ths of an Inch.
Minutes.			Minutes.		
0·00			2·30	0·185	
0·05	0·000	0·000	2·38	..	0·230
0·10	0·000		2·45	0·190	
0·20	..	0·070	2·55	..	0·235
0·28	0·040		3·00	0·200	
0·35	.	0·100	3·10	..	0·245
0·45	0·080		3·18	0·210	
1·00	..	0·145	3·25	..	0·250
1·10	0·120		3·33	0·215	
1·20	..	0·170	3·40	..	0·255
1·28	0·135		3·48	0·220	
1·55	..	0 200	3·55	..	0·260
2·15	0·175		3·08	0·220	
2·20	..	0·220			

Load, 5½ tons. ▯ 60 ↓↓.

0·00	..	0·000	2·15	0·295	..
0·05	0·000		2·20	..	0·325
0·10	..	0·075	2·28	0·305	
0·15	0·090		2·35	..	0 340
0·50	..	0·195	2·43	0·310	
0·55	0·185		2·50	..	0·350
1·00	..	0·210	2·53	0·325	
1·08	0·195		3·05	..	0·370
1·13	..	0·230	3·10	0·345	
1·18	0·210		3·15	..	0·375
1·30	..	0·275	3·18	0·345	
1·40	0·245		3·40	0·370	0·395
1·45	..	0·290	3·55	..	0·400
1·50	0·270		4·00	0·375	
2·00	..	0·300	4·15	..	0·410
2·03	0·280		4·20	0·385	
2·09	..	0·310			

TABLE XVI.—TIME-EFFECT of LOAD HIGHER THAN THAT AT WHICH THE LIMIT of ELASTICITY WAS REACHED.

Load, 14½ *tons at the centre.*

Conditions, I 60 ↓ ↓. Strains measured on 7½ inches.

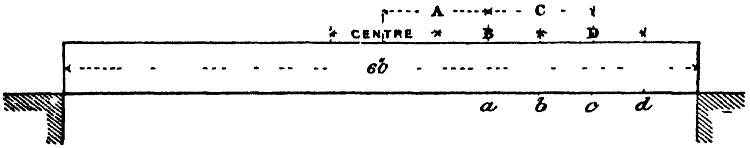
Time.	Tension, 100ths of an Inch.	Compression, 100ths of an Inch.	Time.	Tension, 100ths of an Inch.	Compression, 100ths of an Inch.
Minutes.			Minutes.		
0·00	0·000	0·000	3·04	0·657	
0·09	0·000		3·27	..	0·597
0·54	..	0·107	3·35	0·727	
1·06	0·257		4·05	..	0·667
1·32	0·407	0·267	4·11	0·782	
1·46	..	0·317	4·30	..	0·697
1·58	0·482		4·35	0·807	
2·16	..	0·417	4·46	..	0·717
2·28	0·577		5·00	0·832	
2·54	..	0·517	5·29	..	0·767

Load, 15 *tons.* I 60 ↓ ↓. .

0·00	..	0·000	2·46	..	0·760
0 05	0·000		3·03	0·625	
0·12	..	0·150	3·13	..	0·800
0·15	0·100		3·24	0·650	
0·25	..	0·250	3·32	..	0·825
0·34	0·200		3·45	0·675	
0·37	..	0·300	4·08	..	0·875
1·03	..	0·450	4·14	0·700	
1·05	0·350		4·29	..	0·900
1·13	..	0·500	4·36	0·725	
1·19	0·400		4·59	..	0·925
1·31	..	0·575	5·09	0·750	
1·37	0·460		6·07	..	0·970
1·58	..	0·650	6·12	0·790	
2·05	0·525		7·08	..	1·000
2·26	..	0·720	7·21	0·820	
2·37	0·590				

TABLE XVII.—

Fig. 11.



Load at Centre of Span.		Centre.				A.			
		Extension, 1,000ths of an Inch.		Deflections, 50ths of an Inch.		Extension, 1,000ths of an Inch.		Deflections, 50ths of an Inch. a	
▭	▯	▭	▯	▭	▯	▭	▯	▭	▯
44·48	88·96	0·00	0·00	0·0	0·0	0·00	0·000	0·00	0·0
88·96	177·92	1·028	1·026	5·5	3·5	1·02	0·898	4·00	2·0
133·44	266·88	2·56	2·31	11·0	..	2·05	1·920	8·50	5·0
..	..	3·84	3·60	15·0	..	3·34	3·080	12 50	6·5
..	..	5·39	4·88	21 0	..	4·62	4·240	17·50	8·5
..	..	7·05	6·15	26·5	..	5·90	5·400	22·50	10·5
..	..	8·72	7·70	31·5	18 5	7·19	6·420	26·50	12·5
..	..	10·52	9·25	37·5	21·5	8·60	7·700	31·50	14·5
..	.	12·18	10·78	42·5	24 0	10·13	9·250	35 50	16·5
..		14·00	12·57	48 0	27 0	11·68	10·650	40·00	19·0
..	..	0·38	..	0 0	..	0·00	0·380	0·00	0·0
								Span =	
44·48	88·96	0·00	0·00	0·0	0·0	0 00	0·000	0·00	0 0
88·96	177·92	0·77	0·77	..	1·5	0·61	0·900	2 50	2·0
133·44	266·88	1 66	0·66	6 0	3 5	1·80	2 050	5 00	3·0
..	..	2 56	2·97	9·5	5·5	2·70	3·210	7·50	4·5
..	..	3·47	4·24	12·5	6 5	3·72	4·240	9·50	5·3
..	..	4 88	5·26	15·0	8 5	4 88	5·400	12·00	7·0
..	..	5·75	6·28	18·5	9·5	5·91	6·670	14 50	7 5
..	.	7·06	7 43	22·5	11·0	7·05	7·950	17·50	9·0
..	..	8·48	9·11	24·5	12·0	8 34	9·250	19·50	10·0
..	.	9·76	10·53	27·5	13·5	9·62	10·520	22·00	11·0
..	..	0·25	0·00	0·0	0·0	0·38	0·250	0·00	0·8
								Span =	
44·48	88·96	0·00	0·00	0·0	..	0·00	0·000	0 00	0·0
88·96	177·92	0·77	0·77	..	..	0·64	0·900	0·50	0·5
133·44	266·88	1·53	1·66	0·0	0·0	1·15	1·650	2·00	1·0
..	..	2·31	2·56	1·0	..	1·92	2·560	2·50	2·0
..	..	3·34	3·20	3 0	2·0	2·57	3·340	3·00	2·0
.	.	4·00	4·00	4·0	..	3·48	4·100	3 75	3·0
..	..	5·00	4·75	5·5	3·5	4·35	4·750	4·50	3·0
.	..	6·28	5·78	7·0	..	5·00	5·390	6·00	4·0
..	.	7·30	6·80	9·0	..	5·78	6·420	7·00	4·5
..	..	8·33	7·70	10·0	6·0	6·80	7·440	7·50	5·5
..	..	0·00	0·64	..	..	0·38	0·000	..	..

Load at Centre.

Load increased in all spans by equal increments of 44·48 lbs. for ▭ and 88·96 lbs for ▯. Extensions measured over lengths of 10 inches indicated by capitals. Deflections measured at points indicated by small letters.

Single Loading.

Span = 60 inches.

B.				C.				D.			
Extension, 1,000ths of an Inch.		Deflections, 50ths of an Inch.		Extension, 1,000ths of an Inch.		Deflections, 50ths of an Inch.		Extension, 1,000ths of an Inch.		Deflections, 50ths of an Inch.	
		b				c				d	
▭	▯	▭	▯	▭	▯	▭	▯	▭	▯	▭	▯
0·00	0·00	0·00	0·00	0·00	0·00	0·0	0·0	0·00	0·00	0·0	0·0
0·00	0·64	3·50	2·00	0·64	0·77	2·5	0·5	0·38	0·38	2·0	0·5
1·54	1·54	6·50	4·00	1·28	1·28	5·0	1·0	0·77	0·77	3·0	1·5
..	2·43	10·50	6·00	1·80	2·18	7·5	3·0	1·15	1·02	4·0	2·0
3·48	3·34	14 50	8·00	2·30	2·95	10·0	4·5	1·54	1·54	5·0	3·5
..	4·50	17·50	9·00	2·97	3·85	12·5	6·0	1·94	1·94	6·0	3·0
5·26	5·40	21·00	10·50	3·60	4·62	15·0	6·5	2·30	2·30	8·0	4·0
..	6·40	25·50	12·00	4·36	5·40	18·5	8·0	2·84	2·70	10·0	4·5
7·18	7·30	28·50	14·00	5·13	6·28	21·5	9·0	3·34	3·20	10 5	5·0
8·34	8·34	32·50	16·50	5·78	7·20	23·5	10·5	3·85	3·60	12·0	6·0
0·00	0·00	0·00	0·00	0·00	1·28	0·0	0·0	0·51	0·00	0·0	0·0
50 inches.											
0·00	0·00	0·00	0·00	0·00	0·00	0·0	0·0				
..	0·64	2·00	0·70	0·38	0·38	1·0	1·5				
1·28	1·28	4·00	2·20	0·90	0·77	2·0	1·5				
..	1·92	5·50	3·20	1·28	1·02	3·0	2·5				
2·83	2·70	7·50	4·20	1·66	1·41	4·0	3·0				
..	3·46	9·00	5·70	2·18	1·80	4·5	4·0				
4·24	4·36	10·50	5·70	2·83	2·31	5·5	4·0				
..	5·13	12·50	6·70	3·35	2·70	6·5	4·5				
5·64	6·03	14·00	7·20	3·85	3·10	7·0	4·5				
6·67	6·80	16·00	8·00	4·35	3·60	8·0	5·0				
0·25	0·00	0·00	0·50	0·38	0·00	0·0	0·8				
40 inches.											
0·00	0·00	0·00	0·00								
0·51	0·38	1·00	0·50								
0·90	0·77	1·50	1·00								
1·28	1·15	1·75	1·50								
1·93	1·66	2·00	1·50								
2·56	2·18	2·25	2·00								
2·96	2·70	2·50	2·00								
3·60	3·34	3·50	2·50								
4·00	3·85	4·00	2·50								
4·48	4·35	4·00	2·75								
0·00	0·00										

TRANSVERSE MODULUS FROM CAST-IRON BEAM.

	Lbs. per Square Inch.
60 ↓ ▯	E = 10,100,000
60 ↓ ▭	E = 11,235,000
50 ↓ ▯	E = 11,645,000
50 ↓ ▭	E = 11,280,000
40 ↓ ▯	E = 11,405,000
40 ↓ ▭	E = 10,366,000
40 ↓ ▭	E = 12,175,000
Mean	11,172,000

These values are calculated from deflection measurement as far as 16,000 lbs. per square inch on the outer fibre. The tensile modulus, as obtained from the test-piece in Table I, at 4,000 lbs. per square inch is 12,500,000, whereas the mean modulus as far as 16,000 lbs. per square inch, which would be more comparable with the above results, is 10,44 00 lbs. per square inch.

EXTENSION of OUTER FIBRES of CAST-IRON BARS, 63 inches by 2 inches by 1 inch.

Strain measured on 10 inches, at the centre of the span, a constant bending moment obtaining over this length.

Span.	Mean Strain deduced from observations from 20,000 to 1,000 lbs. per Square Inch. 1,000ths of an Inch.		Mean of II and III.
I.	▯ II.	▭ III.	IV.
Inches. 60 ↓ ↓	0·630	0·615	0·622
50 ↓ ↓	0·782	0·769	0·775
40 ↓ ↓	0·769	0·906	0·837

Mean strain for a mean stress of 1,000 lbs. per square inch $\left(S = \frac{M}{Z}\right)$ on outer fibre at various points throughout span of cast-iron beam.

—	Position.	Mean Strain in 1,000ths of an Inch.	—	Position.	Mean Strain in 1,000ths of an Inch.
60 ↓ ▯	A	0·689	50 ↓ ▯	A	0·777
	$B \times \frac{5}{4}$	0·725		$B \times \frac{4}{3}$	0·768
	$C \times \frac{5}{3}$	0·664		$C \times 2$	0·582
	$D \times \frac{5}{2}$	0·594	50 ↓ ▭	A	0·803
				$B \times \frac{4}{3}$	0·714
60 ↓ ▭	A	0·770		$C \times 2$	0·736
	$B \times \frac{5}{4}$	0·689	40 ↓ ▯	A	0·751
	$C \times \frac{5}{3}$	0·618		$B \times \frac{3}{2}$	1·020
			40 ▭	A	0·751
	$D \times \frac{5}{2}$	0·606		$\times \frac{3}{2}$	1·189

Supplementary Experiments on Cast-Iron.

Dimensions of cast-iron bar and test-pieces used in the supplementary experiments on cast-iron:—

Beam, 3·18 inches by 1·54 inch, $Z = 2·596$.
Tensile test-piece, No. 1 diameter = 0·754 inch; area, 0·446 square inch.
" " No. 2 } not used.
" " No. 3 }

The strains on No. 1 were measured on 10 inches, the test-piece being turned for 11½ inches It was held by Professor Kennedy's ball-and-socket holders, thus eliminating any inaccuracy of pull due to wear in the testing-machine

The strains were measured by Professor Kennedy's new extensometer, giving simultaneously the mean of both sides.

Specimen for compression:—

Diameter	1·755 inch.
Area	2·419 square inches.
Length	7·00 inches.

The strains on this specimen were measured on 5 inches.

The strains on the beam were measured on 7½ inches, but are reduced to an equivalent strain on 10 inches in order to compare with other measurements.

Tension.

Particulars of Experiment.—Tension. Cast-iron test-piece same material as cast-iron beam in supplementary experiments.

Dimensions of specimen, 0·754 inch in diameter. Area, 0·4465 square inch. Extensions measured on 10 inches.

Total Load.	Stress per Square Inch.	Extension. 100ths of an Inch.	Total Load.	Stress per Square Inch.	Extension. 100ths of an Inch.
Lbs.	Lbs.		Lbs.	Lbs.	
0	0	0·000	5,500	12,320	1·120
500	1,120	0·070	6,000	13,440	1·240
1,000	2,240	0·175	6,500	14,560	1·355
1,500	3,360	0·265	7,000	15,680	1·480
2,000	4,480	0·365	7,500	16,800	1·600
2,500	5,600	0·465	8,000	17,920	1·735
3,000	6,720	0·565	8,500	19,040	1·855
3,500	7,840	0·670	9,000	20,160	1·990
4,000	8,960	0·790	9,500	21,280	2·130
4,500	10,080	0·890	0	0	0·000
5,000	11,200	1·010			

Particulars of Experiment.—Compression. Cast-iron test-piece same material as beam in supplementary experiments.

Dimensions of specimen, 1·755 inch in diameter. Area, 2·419 square inches. Extensions measured on 5 inches.

Total Load.	Stress per Square Inch.	Compression. 1,000ths of an Inch.	Total Load.	Stress per Square Inch.	Compression. 1,000ths of an Inch.
Lbs.	Lbs.		Lbs.	Lbs.	
10,000	4,134	0·000	60,000	24,804	0·870
15,000	6,200	0·070	65,000	26,870	0·960
20,000	8,268	0·160	70,000	28,940	1·040
25,000	10,330	0·260	75,000	31,010	1·130
30,000	12,402	0·340	80,000	33,072	1·225
35,000	14,470	0·430	85,000	35,140	1·320
40,000	16,536	0·525	90,000	37,206	1·425
45,000	18,603	0·620	95,000	39,280	1·510
50,000	20,660	0·700	100,000	41,340	1·620
55,000	22,740	0·780	10,000	4,134	0·000

Particulars of Experiment—Cast-iron bar 62 inches long, machined all over. Dimensions of specimen, rectangular section 3·18 inches by 1·54 inch; area, 4·89 square inches; Z = 2·596; span 60 inches; double knife-edge. Extensions measured on 7½ inches.

Total Load.	Stress per Square Inch.	Compression. 100ths of an Inch.	Extension. 100ths of an Inch.
Tons.	Tons		
0	0·00	0·000	0·000
¼	1·12	0·140	0·170
½	2·24	0·300	0·350
¾	3·36	0·465	0·540
1	4·48	0·630	0·735
1¼	5·60	0·795	0·935
1½	6·72	0·960	1·125
1¾	7·84	1·135	1·345
2	8·96	1·305	1·545
2¼	10·08	1·480	1·775
2½	11·20	1·660	2·000
2¾	12·32	1·845	2·400
0	0·00	0·085	0·000

Particulars of Experiment—Same bar as in preceding Table. Strains measured over 7½ inches in position A (for meaning of position A, see Fig 11) Span 60 inches. Single knife-edge. Extensions measured on 7½ inches.

Total Load	Mean Stress per Square Inch.	Compression 100ths of an Inch Scale Reading	Extension. 100ths of an Inch Scale Reading.
Tons.	Tons		
0	0·00	0·000	0·000
¼	1·08	0·140	0·190
½	2·16	0·305	0·365
¾	3·24	0·475	0·540
1	4·33	0·635	0·725
1¼	5·41	0·785	0·915
1½	6·50	0·955	1·105
1¾	7·58	1·105	1·300
2 .	8·67	1·260	1·495
0	0·00	0·000	0·000

Particulars of Experiment.—Same bar as in preceding Tables. Strains measured over 7½ inches in position B.

Span 60 inches. Single knife-edge. Extensions measured on 7½ inches.

Total Load.	Mean Stress per Square Inch.	Compression. 100ths of an Inch. Scale Reading.	Extension. 100ths of an Inch. Scale Reading.
Lbs.	Tons.		
0	0·00	0·000	0·000
¼	0·72	0·095	0·095
½	1·44	0·195	0·195
¾	2·16	0·290	0·295
1	2·88	0·385	0·395
1¼	3·61	0·485	0·510
1½	4·33	0·580	0·615
1¾	5·05	0·675	0·725
2	5·77	0·770	0·835
0	0·00	0·010	0·000

Deflections at various points throughout the span of cast-iron bar (as in preceding Tables).

Load.	Deflections in 10ths of an Inch.			
	Centre.	5 Inches from Centre	10 Inches from Centre.	15 Inches from Centre
Tons.				
0	0·00	0·00	0·00	0·00
¼	0·50	0·48	0·40	0·33
½	1·04	1·00	0·86	0·70
¾	1·60	1·52	1·32	1·07
1	2·15	2·05	1·80	1·45
1¼	2·77	2·60	2·29	1·85
1½	3·40	3·20	2·80	2·26
1¾	3·96	3·71	3·25	2·65
2	4·52	4·25	3·64	3·03
0	0·00	0·00	0·00	0·00

Owing to the variation of the tensile modulus of cast-iron, it is impossible to give such a summary as in the case of the steel beams The figures are given for each experiment, and an analysis for comparison must be made by judging what should be considered the mean modulus to be introduced into the various formulas.

See Plate 5, Fig. 6, in which some of the results of the foregoing Tables are plotted as curves.

(*Students' Paper No. 254.*)

"The Cyclical Velocity-Variations of Steam and other Engines."[1]

By Herbert Byrom Ransom, Stud. Inst. C.E.

The term "Cycle," as it will be used in this Paper with regard to heat-engines, arose at the commencement of the century when Carnot published his famous theory of the perfect reversible engine.

A complete cycle is one large process, consisting of the four minor processes: (1) Increase of volume at constant temperature; (2) Adiabatic expansion; (3) Compression at constant temperature such that when (4) the volume is further diminished to the original volume without the substance being allowed either to admit or absorb heat.

These conditions cannot be rigidly adhered to in practice, and in the steam-engine they would be graphically represented by its indicator diagram. Hence the ordinary simple double-acting steam-engine has two complete cycles in one revolution of the fly-wheel. Gas-engines, on the other hand, vary considerably, from the Atkinson which has one cycle to one revolution, to the Griffin and Beck engines with one cycle to every three revolutions.

The term cycle, as applied to recent gas-engines, is, therefore, very much modified from the original use of the word.

The rest of the title needs very little comment, except that no attempt will be made to suggest any law governing the fluctuations. It is in the first place doubtful whether considering the number of variable quantities involved, such as steam-pressure, speed, cut-off, friction and resistance, a practical law could be formulated; and secondly, a far greater number of experiments than have hitherto been made, and under all the varying conditions, would have to be undertaken afresh, supposing the instrument about to be described were absolutely accurate.

---

[1] This communication was read and discussed at a meeting of the Students on the 22nd of March, 1889, and was awarded a Miller prize in the Session 1888–89.

It may seem a trivial matter whether an engine varies its speed during one cycle or not, since it might naturally be supposed that the variation in such a small space of time would be itself very small; but any one acquainted with the delicate nature of the work done in spinning and textile factories also knows that very small fluctuations may cause the breakage of thousands of threads, and consequently, the stoppage for a time of a corresponding number of spindles. This difficulty is so great that engines designed for such purposes have enormous fly-wheels and very excellent governors. The use of compound engines, with the cranks arranged at an angle, has recently modified matters; but nevertheless, the fact that small fluctuations are very dangerous and have never been accurately measured remains true.

Again, for electric lighting purposes, it is important to obtain an evenly-running engine. In the earlier years of electric lighting, attempts were made to take the current direct from the dynamo to the lights, the prime mover being an Otto or other gas-engine. Obviously, the gas-engine having only one impulse to every one, two, or even three revolutions, ran very irregularly, and the light varied according as the engine was receiving an impulse or merely pumping or compressing a charge.

These two examples show that the experiments, undertaken by the Author, were not merely laboratory experiments, but were attempts to remedy an acknowledged evil by first measuring its amount.

DESCRIPTION OF THE APPARATUS.

The apparatus, made by Messrs. Manlove, Alliott & Co. (Figs. 1), was very simple, and is described in the Journal of the Society of Arts in connection with the trials of motors for electric lighting.[1]

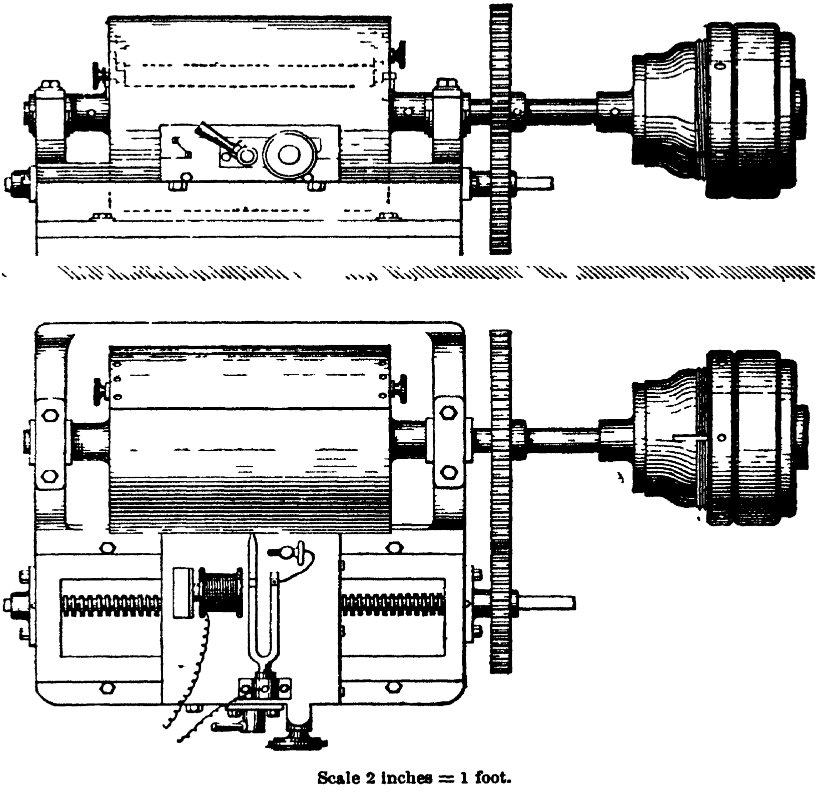
The main idea is to make an instrument to record equal intervals of time, mark its beats on a drum rigidly fixed to and turning with the unequally revolving fly-wheel. The time-recorder in this instrument is a tuning-fork of 500 pitch, stimulated electrically.

Firmly fixed to one prong is a piece of very light beaten-out brass, stiffened horizontally, until within $\frac{1}{4}$ inch of the point, by being made semi-cylindrical in section, the other prong being carefully balanced to match. The drum is keyed on to a $\frac{1}{2}$-inch steel spindle supported by two bearings on a cast-iron bed-plate. The spindle should be attached to the end of the crank-shaft in such a way that it cannot move without the crank-shaft. The tuning-fork is carried on an ordinary lathe tool slide-rest, which in its turn is clamped to the bed-plate carrying the drum. Toothed wheels are keyed on to the drum-spindle and on to a screw, which gives the rest a horizontal motion parallel to the axis of the drum.

---

[1] Journal of the Society of Arts, 1889, vol. xxxvii. p. 242.

Figs. 1.



Scale 2 inches = 1 foot.

The remaining motion of the slide-rest, namely, in a direction at right-angles to the drum axis, enables the worker to throw the toothed wheels into or out of gear at will.

The connection of the drum-spindle to the engine-shaft used in the first trials was made as follows. The drum-spindle was tapered about ½ inch at the extremity, and fitted into a corresponding conical hole in the end of the crank-shaft, to which was fixed a small gun-metal crank of about 2 inches radius, the pin of which entered a small disk fixed on the end of the spindle. The spindle was kept tight in the conical hole by means of a flat spring pressing on its outer end.

By this arrangement it is possible, with engines running up to 100 revolutions, to throw the spindle into and out of gear without stopping the engine.

It has been previously stated that the tuning-fork carried a pen. The drum was covered with specially prepared tightly drawn smoked paper, and the whole was so arranged that when the teeth of the wheels properly geared, the tip of the pen just lightly touched the smoked paper.

The tip of the pen was bent so as to point tangentially to the surface of the drum, and the drum itself rotated in the same direction that the tip pointed.

The object of all these precautions was to lessen the friction between the pointer and the paper. The friction probably would not alter the period of the wave, but it certainly would alter its amplitude.

In fixing the paper on the drum it is prudent to arrange so that the lap-joint may come at an unimportant part of the curve. It must then be smoked with camphor soot, and at the same time all moisture in the paper, which must be put on damp, removed, the paper thereby becoming taut.

FIRST EXPERIMENTS ON THE STEAM-ENGINE, UNIVERSITY COLLEGE, LONDON.

The engine used was that belonging to the University College, London, Engineering Laboratory, which, through the kindness of Professor Kennedy, was placed at the Author's disposal. It is a tandem compound condensing-engine of about 15 indicated HP., steam-jacketed in both cylinders, and is of a type still often built by Messrs. Donkin for pumping purposes. It has a very heavy fly-wheel, and the air-pump is worked direct off the connecting-rod by means of a link.

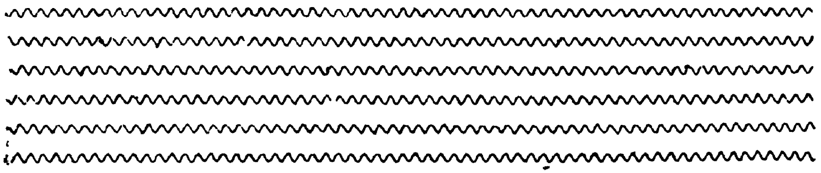
The engine worked for the first two or three trials with the air-pump on, but it was disconnected for the remainder, the Author thinking at the time that this might materially influence the fluctuations, by suddenly applying a severe load on the connecting-rod just at its rise on the forward stroke.

After the engine was adjusted as to resistance speed and cut-off, the drum-spindle was pushed into gear with the crank-shaft, and the tuning-fork, stimulated by two or three Grove's cells.

At a given instant, by turning the handle giving the tuning-fork a motion towards the drum, the toothed wheels came into gear, and the pen just lightly touched the paper. The fork was now carried horizontally along the drum, describing a spiral consisting of small waves for some twenty continuous revolutions on its surface; the tuning-fork was then withdrawn from the paper and the engine could be stopped. The total number of vibrations shown on the drum (Fig. 2) was checked by a stop-watch, it being started at the instant the pen touched the paper and stopped at the instant of leaving it.

Then, by adding up the number of vibrations on the drum paper, and assuming that the maker's statement, that the pitch of the fork was correct, namely 500 vibrations to the second, the result could be compared with the result obtained by the stop-watch, and at the same time that the pen was in contact with the paper, four indicator diagrams were taken. The position of the paper with reference to the pen when the engine was on either centre was carefully marked, and then the paper would be removed, varnished and hung up to dry.

FIG. 2.



FAC-SIMILE of CURVES OBTAINED with CYCLOMETER from STEAM-ENGINE of UNIVERSITY COLLEGE, LONDON.

Taking for example trial No. 5 (Plate 6, Figs. 1 and 2):—The conditions of working were: boiler-pressure, 85 lbs.; brake HP., 3·67; early cut-off; non-condensing; the instrument recorded 18·8 revolutions; and the mean number of waves in each revolution was 394. Therefore the revolutions per minute were 76·2. The method of scaling adopted was as follows. The number of waves representing 1 revolution were ticked off by tens starting from the wave corresponding to the front centre of the engine. A length enclosing the length of the first ten waves was taken by compasses, and plotted along a horizontal straight line. Five times this length plotted vertically gives the mean velocity over this portion of the curve on some scale.

By this plotting every length of ten waves during the revolution, a complete curve, whose ordinates represents the velocity of the fly-wheel at any point, may be obtained. Great care has to be taken in measuring off the lengths of the sets of ten waves. It frequently happens that the pointer, especially if the camphor black on the drum-paper be too thick, throws off the fine particles on each side of its true path. This can easily be avoided by only lightly smoking the drum; but should it occur by some mischance, greater care must be exercised in plotting. Another precaution is to take the mean of the lengths of ten waves, starting from those immediately adjoining the wave which happens to be the first of the group whose united length is to be measured.

In the case in point there are, in the first revolution, for example, 402·5 waves; therefore the time of revolution $= \frac{402 \cdot 5}{500}$ seconds $= 0 \cdot 805$ second.

This is equivalent to 74·5 revolutions per minute.

On the drum the length of these 402·5 waves is 18·6 inches; therefore $\frac{18 \cdot 6}{402 \cdot 5} \times 10 =$ mean length of 10 waves $= 0 \cdot 464$ inch.

Let the mean crank-pin velocity $= 5 \times 0 \cdot 464$ inch $= 2 \cdot 32$ inches. The stroke is 12 inches; therefore $\frac{3 \cdot 1416}{0 \cdot 805} = \frac{\text{circumference}}{\text{time of this revolution}}$ = mean crank-pin velocity in feet per second $= 3 \cdot 9026$ feet per second.

On paper, 2·32 inches = 3·9026 feet per second; or 1 inch = 1·68 foot per second = scale for the crank-pin velocity. In this way several revolutions in each trial were plotted.

It obviously was of the greatest importance to have an independent check upon the results thus experimentally obtained. For this purpose the author in each experiment took a set of indicator diagrams, and, having corrected them for the inertia of all the reciprocating parts, drew the corrected crank-pin pressure or twisting-moment diagram plotted to the rectified path of the crank-pin as base. By drawing a horizontal at the mean height of this diagram the area representing the fluctuation of energy may easily be ascertained. Then, if the weight of the fly-wheel be accurately known and reduced to crank-pin radius, the following formula generally used for obtaining the weight of the fly-wheel rim to be used for a given fluctuation, can be applied.—

$$V_2 - V_1 = \frac{E\,g}{W\,n^2\,V_0}.$$

Where V_1 = minimum crank-pin velocity in feet per second;
V_2 = maximum " " "
V_0 = mean " " "
(Calculated for each revolution.)
$n = \frac{\text{radius of gyration of fly-wheel}}{\text{crank-pin radius}} = 4\cdot46$;
E = area representing the transference of energy corresponding to the change of velocity $V_2 - V_1$;
W = weight of fly-wheel rim in lbs.;
g = 32·2 feet per second.

In this part of the work it was of the greatest advantage to have used a laboratory engine, since the weight and dimensions of every part had been frequently accurately determined both by the Author and by many other persons. Nevertheless, though the formula is founded on sound theoretical reasoning,[1] several assumptions have necessarily been made in its construction.

In the first place, the friction throughout the engine has been neglected; and secondly, the mean velocity V_0 has been assumed to be the arithmetic mean between the maximum and mean velocities, or that

$$V_0 = \frac{V_1 + V_2}{2}.$$

Also the connecting-rod is assumed as acting with one-half its weight at the cross-head and one-half at the crank-pin. There also is a fourth assumption, which in the Author's opinion is not quite unimportant. The fluctuation area (E) is found by drawing a horizontal straight line at the mean height of the twisting-moment diagram. It is said that the resistance during 1 revolution may be assumed to be constant; but obviously this need not be so, and, to those who have ever had to manage a brake at an engine trial, it would seem to be very doubtful. If the resistance does vary, then the horizontal straight line should be altered to some irregular wavy line representing the change in resistance throughout the stroke. Further, if the engine is gaining or losing in speed, the fluctuation area would be larger or smaller than the area cut off by a horizontal straight line at the mean height of the twisting-moment diagram.

---

[1] "The Mechanics of Machinery." By Alex. B. W. Kennedy. 1886.

In the first case the net value of E would be the same, but it would probably alter the positions of the maximum and minimum velocities, and in the second case neither the amount of E nor the positions would be correct. An instrument to measure and record the variations in resistance has been used in America by Professor Thurston.[1] Hence the fluctuations as determined by means of this formula are probably only approximate, and the finding of E entails a long and elaborate construction before even this approximation can be arrived at.

A still further test, based on the former, was also carried out in several trials. Seeing that the twisting-moment diagram represents the varying pressures on the crank-pin at each point of its path, the same diagram with the mean height as base-line will be an acceleration curve in some unknown scale. Further, if this be an acceleration diagram, and the velocity at some point of the crank-pin path be known, the corresponding crank-pin velocity diagram can be deduced from it and compared with that found by experiment.

An assumption must again be made with regard to the relation between V_0, V_1, V_2, in order to find the magnitude of the maximum velocity.

Assuming, however, as before that $V_0 = \frac{V_1 + V_2}{2}$, and knowing also from theoretical reasons the position of the maximum velocity, its magnitude may be determined from the two equations

$$\left.\begin{aligned} V_0 &= \frac{V_1 + V_2}{2} \\ V_2 - V_1 &= \frac{E g}{W n^2 V_0} \end{aligned}\right\}.$$

The scales, of course, are different from what they were for the previous curves, but they can readily be determined by the methods recommended by Professor Kennedy. Several experimental curves have been plotted on the same scale for comparison, and on the whole the two agree fairly well. An important point to notice is that the positions of the maxima and minima, as found by experiment, agree very closely with those suggested by theoretical reasoning.

---

[1] Transactions of the American Society of Mechanical Engineers, vol viii. p. 86; and *Engineering*, 1889, vol xlvii p 22.

The annexed Table shows the results of some of the trials undertaken, and also the results obtained theoretically :—

Trial.	Revolutions.		Velocity in Feet per Second.				$\frac{Eg}{W n^2 V_0}$.	Fluctuation, per cent.	Number of Waves, 100 Waves = $\frac{1}{8}$ second
	F.	B.	Maximum.	Minimum.	Mean.	Difference.			
5*	1	..	3·920	3·820	3·900	0·1000	0·1270	2·56	402·5
5	..	1	3·930	3·780	3·900	0·1500	0·1210	3·85	402·5
5	15	..	4·015	3·920	4·000	0·0815	0·1230	2·04	392·3
5*	..	15	4·025	3·895	4·000	0·1300	0·1160	3·25	392·3
5	21	..	4·000	3·920	4·000	0·0800	0·1230	2·00	392·0
5	..	21	4·030	3·915	4·000	0·1150	0·1160	3·08	392·0
6	..	1	5·070	4·960	5·025	0·1100	0·1006	2·19	312·6
6	..	3	5·100	5·000	5·040	0·1000	0·1000	1·99	311·4
6	..	5	5·130	5·025	5·080	0·0950	0·0993	1·87	309·0
6*	..	19	5·130	5·000	5·055	0·1300	0·0998	2·58	313·1
6	..	21	5·100	·960	5·056	0·1400	0·0997	2·77	313·3
2	..	1	5·035	4·875	4·960	0·1600	0·0915	3·23	317·0
2	1	..	5·020	4·910	4·960	0·1100	0·0915	2·22	317·0
2	..	14	5·000	4·835	4·910	0·1650	0·0920	3·36	320·2
2	14	..	5·040	4·840	4·910	0·1600	0·0920	3·27	320·2

N.B.—The asterisk denotes unreliability.

It should be noticed that an increase in the number of waves per revolution, that is, a diminution in speed, almost always brings with it an increase in the fly-wheel velocity-fluctuation; and conversely, an increase in speed, as shown by a diminution in the number of waves per revolution, brings with it a diminution in the fluctuations. This obviously should be so if the formula $\frac{E g}{W n^2 V_0}$ is correct.

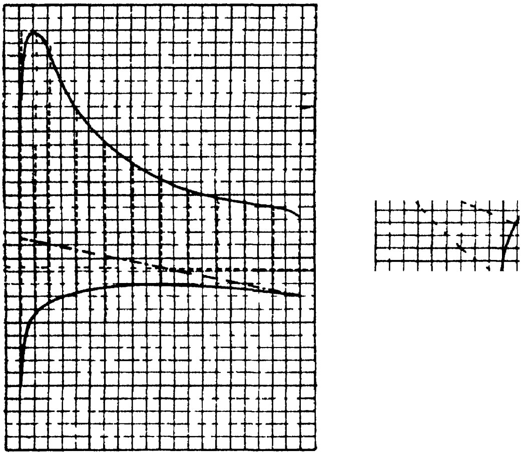
In most cases the maximum velocity is less in the forward stroke than in the back stroke (the engine running clockwise), the minimum also is less.

The fluctuation therefore becomes greater in the back stroke. Nevertheless, in the self-same cases the reverse should be true if the value of $\frac{E g}{W n^2 V_0}$ were correct. On the face of things it would appear that the maximum in the forward stroke should be less than that in the back stroke, because some of the reciprocating parts are rising then, and falling during the back stroke.

GAS-ENGINE TRIALS.

For the velocity diagrams and curves of the gas-engine the Author is indebted to the kindness of Professor Kennedy (Figs. 3). The engine was a 9-inch (stroke) by 4½-inch (cylinder diameter) Crossley Otto, of recent make. The trials were undertaken by Mr. Forbes, in October, 1888, under several different conditions, such as engine running light, with full load, and in transition state. The velocity curve was deduced by the same methods from the indicator diagram as has been described. The cards were, however, not taken from this particular engine, but from another of similar make, and using the same volume of gas.

FIGS 3



Scales Space, 1 inch = 6 75 inches, pressure, 1 inch = 150 lbs per square inch

OTTO INDICATOR DIAGRAM, and CRANK-PIN PRESSURE DIAGRAM

Seeing that the machines in question are gas-engines of the same type, and that there are no variable cut-offs, and that the gas was the same in both cases, it is assumed that the cards can give no important variation.

One fact, however, should be noticed, that in finding the fluctuation theoretically it becomes a difficult operation to discover with accuracy the mean velocity for any 3 or 4 revolutions which may be analyzed. The reason is that, as the Otto engine has only one impulse to every 2 revolutions, and that it is governed by missing out an entire explosion, the fluctuations become so great over the dozen revolutions close to the miss, that their mean may vary 15 per cent. from the mean calculated from the revolutions per minute. It may be argued that the same objection holds for the steam-engine; but in that case there are two impulses to 1 revolution, and no misses; that is, there are eight times as many impulses as in the Otto engine when the governor comes into play, and hence the mean velocity does not change nearly so much. The action of the governor is shown very clearly in one trial worked out by Professor Kennedy and Mr. Forbes (Plate 6, Fig. 5). In the diagram 8 consecutive revolutions are plotted, the engine at the time driving a dynamo and giving 71 explosions per minute for 177 revolutions, or about 80 per cent. of the maximum number. In the first cycle the maximum is lower than in the second, and in the third it is higher still; so high, in fact, that the third minimum is greater than the first maximum. The result of this rapid rise of velocity is shown in the seventh revolution; where, were the engine to be running steadily an explosion should occur, an explosion is cut out altogether, as shown by the continued decrease in velocity. The decrease continues steadily until the end of the eighth revolution, at which period the velocity has reached about the same limit as when the curve first started, and consequently in the following revolution an explosion again takes place.

The ratio of the maximum velocity to the minimum reached during the 8 revolutions, during the same period, is 1·14. The percentage calculated from the mean velocity $= \frac{\text{fluctuation}}{\text{mean velocity}}$ $= 13 \cdot 15$.

The percentage of fluctuation during one cycle taken in the same way is 11·50.

The Author is of opinion that, although the numerical results given in this Paper are not sufficient to be of much value, beyond having an interest attached to them as being hitherto practically indeterminate, they are sufficient to show that such an instrument as has been described is capable of performing the duties for which it was designed; and he is also of opinion that it has certain important practical uses. Suppose, for instance, that an engine be required to have great regularity in running, and that the resistance keeps moderately constant, as would be the case in most factory engines. At present the means adopted to secure this are to have a very heavy fly-wheel and good governing arrangements. In consequence, the crank-shaft and bearing surfaces have to be exceptionally strong and large. On the other hand, seeing that in all engines the velocity of rotation during each cycle must vary, there must be some positions (minimums of the crank-pin for which the engine would run easier if the fly-wheel were lighter in order to increase the velocity, and others (maximums) where it would be better for the fly-wheel to be heavier. Hence the conclusion is arrived at that a fly-wheel, whose inertia may be increased or diminished at the positions of maximum and minimum velocity of the crank-pin, to absorb or give out its superabundant or its redundant energy, is desirable, to give a perfectly even velocity of rotation. Further, that if such a fly-wheel were designed, it would probably be lighter than one designed in the ordinary fashion.

The instrument is also useful for testing the action and efficiency of governors, an example of which has been given for the Otto engine trial. It was moreover used by the Committee of the Society of Arts in the recent motor trials, simply to test the regularity of running of the competing engines. Many curves were taken by them, but they were afterwards discovered to be unreliable from the coupling slipping. It should be added that at least one large firm of general engineers is making one of these instruments, in the belief that it will be of use in testing engines, especially gas-engines.

There are several points to which the Author would wish to direct attention. The apparatus must be used carefully. If for high speeds, special arrangements must be adopted for the coupling between the spindle and the crank-shaft, and to enable the worker to give the tuning-fork its horizontal motion at any moment he pleases. Obviously throwing two toothed wheels into gear after the manner described, whilst one of them is running at a high speed, would be a very awkward arrangement. In the cases of very high speeds, no doubt a more highly pitched tuning-fork would be advisable.

In conclusion, the Author begs to acknowledge his indebtedness to Professor Kennedy for the great help and attention shown him during his first experiments, and afterwards for the data of other trials since furnished. Great help was also afforded him by Mr. Forbes and by Mr. Frank Marshall, of University College, London.

The Paper is accompanied by several tracings, from which Plate 6 and the Figs. in the text have been prepared.

(*Paper No. 2383.*)

"Balanced Slide-Valves."

By John Carter Park, M. Inst. C.E.

This communication is illustrative of various forms of balanced or partly balanced slide-valves, which have been from time to time experimented with on the locomotives in use on the North London Railway, with the dates of their introduction (Plate 7, Figs. 1 to 11).

Figs. 1, $\frac{M}{1}$ (1856), show a form of valve having the steam admitted through the steam-chest cover to the inside of the valve, the steam-chest being relieved of pressure and communicating only with the exhaust; the steam-lap in this case is on the inside, which reduces the size of the valve.

Figs. 2, $\frac{M}{95}$ (1863), show a pair of balanced-valves as applied to a six-wheeled coupled goods engine No. 11, having inside cylinders. Each valve is in three pieces, and works between two parallel faces, the valves being fitted with adjustable wedges to take up the wear. The valves were never tight, and the difficulty of obtaining and maintaining parallel faces when hot was so great that they were taken out after a few weeks' trial.

Figs. 3, $\frac{M}{4}$ (1867), show a valve on Thomas Adams' principle, having a relief-ring fitted to the back of the valve, and working between the cylinder-face and the steam-chest cover. The relief ring is kept up to the cover-face by the spring shown. The valve exhausts the steam through the steam-chest cover, the ordinary exhaust-port being blocked up, and the engine had a very free exhaust; it ran for about six months, but the valve ultimately had to be taken out owing to leakage through the relief-ring.

Figs. 4, $\frac{M}{5}$ (1867), show another form of a pair of Thomas Adams' valves, fitted within a very narrow space to an inside-cylinder engine. These valves had two relief-rings, and ran for some six months; they, however, required too much attention to keep tight, and they had to be replaced by the ordinary valves.

Figs. 5, $\frac{M}{6}$ (1868), represent another valve of cast-iron on Thomas Adams' principle, fitted with one large relief-ring; this valve was applied to a standard passenger outside-cylinder engine, and great trouble was experienced in keeping it tight. The back of the valve, though bored out truly to receive the ring, was not found to be round when hot; the ring used to stick, the packing-ring would not remain tight, and although the leakage was reduced to a minimum, still it increased the consumption of fuel, and the valve was replaced by the old one.

Figs. 6, $\frac{M}{7}$ (1869), are a form of valve designed by the late David Park. It was fitted to an outside-cylinder passenger engine. The novel feature in this valve was that a large portion of the load on the valve was taken by the relief-ring and carried on a steel roller running on a bridge-piece inserted over the exhaust-port. This valve soon gave trouble owing to the wear of the roller, and the seizing of the pin; it was replaced by the old valve after two or three months' trial.

Figs. 7, $\frac{M}{10 \text{ and } 12}$ (1871), are two views of Outridge's form of balanced-valves fitted to an outside-cylinder engine. The port face is covered by a plate having the steam and exhaust-passages through it, corresponding to those in the cylinder face. The valve works at right-angles to the ordinary face between two port faces, one being adjustable to take up the wear, and the size of the valve is reduced to about one-half the ordinary size. The plate is free to drop away from the cylinder face when steam is shut off to avoid "pumping," and rests against the stud S. The difficulty in obtaining steam-tight parallel faces was again experienced; but after careful adjusting, the valve was sufficiently tight to run, which it did for some months. The reversing-lever was easily handled, with steam at 160 lbs. per square inch full on, and the wear was very slight on the face of the valve; but constant attention was required to keep it tight, and it was replaced by the old valve, there being no saving of fuel.

Figs. 9, M, represent a pair of Dawe's valves tried on an outside-cylinder engine. In this class of valve the relief-frame is connected to the back of an ordinary valve by a flexible steel diaphragm, so that the valve is practically one piece. Owing to the inability of this valve to leave the faces when running without steam, pumping is set up, causing a partial vacuum in the steam-chest; the diaphragm soon failed and took a permanent set, steam blowing through, and finally it cracked round the frame.

Figs. 10, $\frac{M}{9}$ (1873), show a pair of cast-iron balanced slide-valves designed by Mr. Manico, and tried in No. 63, inside-cylinder passenger engine. There were only two parts in this valve, namely, the valve proper, and the relief-plate. The valve was simply a frame, perforated on its inside and outside edges, to give quick admission and release; the relief-plate had duplicate steam-ports on the inside, and was free to leave the valve when steam was shut off, thus avoiding pumping. The valve was in perfect balance, and the reversing-lever was quite free with steam full on. These valves at first gave promise of success; but, after a few weeks, it was found that the relief-plate, although 1⅜ inch thick, sprang slightly with the pressure, causing the valve to wear hollow and steam to blow through.

Figs. 11, $\frac{\text{M}}{74}$ (1886). This form of valve is similar to the valves in use on the Grand Trunk Railway of Canada, except that the valve works vertically instead of horizontally.

It is simply an ordinary valve with packing-strips fitted to the back to work against the inside face of the steam-chest cover; the packings are kept up to the face by twelve spiral springs, and the steam-chest cover is provided with a port to convey the steam to the front end of the chest. The air-valve opens inwards, and prevents a vacuum being formed when running without steam; a hole drilled in the back of the valve puts the space within the area of the packing-strips in communication with the atmosphere. Although carefully fitted, these valves were never tight, and were replaced by the old valves.

The communication is accompanied by eleven tracings, from which Plate 7 has been engraved.

(*Paper No. 2365.*)

"Underpinning Great Yarmouth Town Hall."

By Frederic Eliot Duckham, M. Inst. C.E.

The new block of municipal offices and law courts at Great Yarmouth was opened by H.R.H. The Prince of Wales, in 1882.

The new structure was 132 feet by 108 feet by 50 feet high to the parapet, with a clock-tower 110 feet high. The whole weighed 5,000 tons, and the cost was £30,000. It was built partly upon, and partly overlapping, the site of the old Town Hall.

The subsoil consisted of a gravel bank, underlying 16 to 18 feet of ooze, and 5 or 6 feet of made ground, into which the trenches were cut for the concrete foundations. The River Yare and its wooden quay-head were 70 feet distant from the west front of the new building.

The structure gave early indications of unequal subsidence; this continued, more particularly in wet seasons and at exceptionally low tides, until early in 1886 it approached the limit of safety, and steps were taken to underpin the worst portion by the insertion of concrete blocks beneath the foundation. The impracticability of removing the water from any trenches cut for this purpose, without at the same time jeopardizing the building, led to this attempt being abandoned, as also was the proposal to widen the foundations by the insertion of wrought-iron needles through the brickwork supported near the surface of the ground on the concrete blocks.

By November 1886, the west or river front of the building, when compared with the east side, was found to have sunk 12½ inches at its ends and 8 inches at its centre, and there were some fissures in it as well as in the north and south walls. The building had not only settled but leaned towards the river. The Town Council therefore resolved to demolish the western portion of the block with the view to its being re-erected on more stable foundations.

A scheme was then submitted to the Town Council by the Author, in conjunction with Mr. James E. Teasdel, Assoc. M. Inst. C.E., of Great Yarmouth, for providing a new foundation which would prevent the further subsidence of the western half of the building, and by means of which the portions which had settled most could be raised to the level of that which had settled least. This proposal also included the straightening and repair of the walls. These works were estimated to cost about half the money, and to occupy one-third the time of the pulling down and rebuilding, previously suggested.

The prominent features of this scheme were:—1st. The insertion of cast-iron screw-piles at intervals of about 9 feet inside and outside the main walls (Plate 8, Fig. 1). These piles were to be about 23 feet long, screwed, say, 3 feet into the gravel bank, the metal to be 1¼ inch thick, the screw to be 12 inches greater in diameter than the piles and of 6 inches pitch, the piles when down were to be cleared of earth and filled with cement concrete. The diameters of the piles were to be 2 feet and 2 feet 6 inches, to carry an approximate weight of, say, 35 to 50 tons respectively; but it being stated that the soil of the district injuriously affected cast-iron, the diameters were increased to 2 feet 6 inches and 3 feet, that, in the event of the iron failing, the internal concrete columns might safely take the weight.

2nd. Double lines of rolled girders, D (Plate 8, Figs. 1, 3 and 7), were placed on top of the piles, with a 2⅛-inch space between them and parallel with the walls.

3rd. Wrought-iron needles, E, 14 feet to 16 feet long, consisting mostly of rolled joists, 16 inches by 6 inches, with a top table added, of a length equal to the width of the original concrete and 12 inches wide, passed through under this concrete foundation at intervals of about 3 feet, to be suspended at each end by two 2-inch bolts, GG, from the before-mentioned girders D. The connections to be made by having a ⅜-inch plate 15 inches square placed on top of the girders, DD, turned down to clip them, and having two 2-inch clearing holes punched therein. Two 7-inch wrought-iron washers, HH, 1½ inch thick on this plate, and one spectacle-piece, 14 inches by 6 inches by 1½ inch under the needle or cross-girder E. The bolts to have 12 inches of thread.

The tower, weighing 700 tons and having a base 20 feet square, to be somewhat differently treated. Five cylinders, two of 4 feet 6 inches and three of 5 feet diameter, to be sunk to the gravel as the adjacent walls permitted. The eastern and western walls of the tower, namely, those without openings on the ground floor, to be each sandwiched between a pair of massive lattice-girders below the floor level (Plate 8, Figs. 1 and 7). Needles of the section shown were to be inserted through the walls, and suspended from the upper member of the girders by four 2-inch bolts at each end. Two platforms of rolled joists were to be laid on the unequally placed cylinders to carry the ends of the four lattice-girders.

It was claimed that the insertion of the needles under the foundations and through the tower walls, and the tightening of the bolts, would transfer the weight of the building from the unstable ground on to the screw-piles, and enable the sunken parts of the building to be raised to level lines, and that an excellent permanent foundation would be obtained at moderate cost.

This proposal of the Author and Mr. Teasdel was adopted, and a contract for the chief portion of the work was entered into with Mr. Thomas Gibson, Assoc. M. Inst. C.E.

The walls having been efficiently shored (Fig. 9), the trenches were cut and the first pile was pitched at the end of May 1887. As the work progressed, the whole western portion of the block and the tower became supported on a sort of gridiron of wrought-iron joists suspended from girders resting on the pile tops (Plate 8, Fig. 1). By a systematic and gradual screwing up of some suspending bolts more than others, the low parts of the building were lifted, the unsightly curves taken out of the walls, and the tower set upright.

The ground was then cleared to a depth of 2 feet under the old foundation of the walls, and the trenches were filled in with cement concrete, forming one mass encasing the pile tops, girders and bolts. The damaged places in the walls were cut out and made good, the floors replaced and the premises refitted for occupation within twelve months.

It should be mentioned that the lifting operation was so well regulated that even the enriched ceiling of the large Assembly Room was not injuriously affected thereby, and that the total cost of the work was well within the estimated sum of £8,250.

The Paper is accompanied by a tracing, from which Plate 8 has been prepared.

(*Paper No. 2419.*)

"On the New Programme for Ship-building."

By W. H. White, F.R.S., M. Inst. C.E.

In the course of the discussion upon Sir Nathaniel Barnaby's Paper on "Armour for Ships,"[1] frequent references were made to the new programme for ship-building embodied in the Naval Defence Act of 1889; and particularly to the eight first-class battle-ships included in that programme.

It occurred to the Author, therefore, that it might be convenient for the members of the Institution, if the Proceedings contained a brief summary of facts respecting this ship-building programme, and a description of the principal features in the design of the first-class battle-ships.

The Admiralty scheme provides for the construction and completion, before the 1st of April, 1894, of seventy additional vessels, viz:—

Eight first-class battle-ships.
Two second " " "
Nine first-class protected cruisers.
Thirty-three second-class protected cruisers, and
Eighteen torpedo gun-boats.

Of these vessels it is proposed to construct thirty-two of all classes in private yards, and thirty-eight in the Royal Dockyards.

It will be noted that all the vessels are to have relatively high speeds, and that all except the eighteen torpedo gun-boats have been designed with protective decks, either in association with vertical side armour, or as the main defence of their vitals.

The protected cruisers of the second class are of two types. The smaller, four in number, are identical with the "Pandora" class of protected cruisers designed for service in Australian waters, of which class five were ordered in 1888 under the provisions of the Imperial Defence Act, and will be completed in the current financial year. In the second class, twenty-nine larger vessels

---

[1] *Ante*, p. 1.

(improved "Medeas") are also included, superior in speed, armament and coal-supply to the "Pandora" type, and about 33 per cent. greater in displacement.

In all these vessels the protective deck is practically identical in character. Its form is indicated on the outline sectional drawing, Plate 9, Fig. 1. The central portion of the deck is horizontal and situated about 1 foot above water; at the sides the deck slopes downwards, and its edges are about 3 or 4 feet under water. This form of deck is maintained over a considerable portion of the length, in order to protect the hold-spaces containing the engines, boilers and magazines. Before and abaft these spaces the protective deck is practically horizontal, and carried to the bow and stern. The rudder-head, steering-gear, &c., are placed under its protection as well as under water. On the "slopes" the deck is formed of 2-inch steel. On the horizontal portions the thickness is 1 inch. Cellular subdivision and coal-bunkers are used as supplemental defences in association with the protective deck as indicated in Plate 9, Fig. 1.

The armament in all the vessels is carried in the open, on the upper deck, forecastles and poops. The guns' crews will be protected by steel shields carried by and revolving with the mountings.

The coal-endurance of these second-class cruisers is very great. With the weights of coal to be carried at the normal load-line and at the speeds named, the "Pandoras" will be capable of covering a distance of 6,000 knots at a speed of 10 knots an hour. The larger vessels of the second class will be capable of steaming about 8,000 knots at the same speed, when starting with bunkers full. These estimates are based upon the assumptions usual in statements of the kind for war-ships of all navies, viz., that the coal is good, that the engines and boilers are in perfect condition, the bottoms of the ships clean, and that the sea is smooth. In actual service these ideal conditions are not realized, of course, many circumstances tending to reduce the distances covered; but the fact remains that the vessels have relatively large coal-supplies.

All these cruisers will be propelled by twin-screws driven by inverted vertical-cylinder engines of the triple-expansion type. The boilers are to be double-ended and of the ordinary Admiralty return-tube pattern, working at a maximum pressure of 155 lbs. per square inch.

The hulls will be constructed of mild steel, with cellular double-bottoms and minute water-tight subdivisions. As the vessels are intended to be employed on general sea-service, and possibly on distant stations where docking accommodation, in time of war at least, may not be available, it is proposed to sheath with wood and copper the bottoms of many of them in order that they may maintain their speeds after being afloat for considerable periods.

The first-class cruisers are vessels of much greater size, heavier armament, stronger protection and larger proportionate coal-supply. The protective decks will have the form shown in cross section by Plate 9, Fig. 2, with a maximum thickness of 5 inches of steel on the slopes. On the horizontal or nearly horizontal portions of the deck the thickness of steel is 2½ inches. As in the second-class cruisers these decks extend from stem to stern, and are associated with cellular subdivision and coal-bunker protection.

The armament mentioned in the schedule above is to be carried chiefly on the upper deck, but partly on the main deck. Its general disposition will resemble that illustrated for the first-class battleships in Plate 9, Figs. 4 and 5. For the protection of the crews of upper-deck guns, strong steel shields of the ordinary character will be provided. At the stations of the main-deck guns, certain novel arrangements are to be made for protecting the guns and their crews, especially from shell fire and high explosives, but of these arrangements no particulars can be given at present.

The coal-endurance is very large. At a speed of 10 knots it is estimated (on the assumptions stated above) that the vessels will be capable of covering a distance of 10,000 knots; in other words, they will have about six weeks' coal on board for their ordinary cruising speed. Their maximum smooth-water speeds on the measured mile are the same as those of the larger second-class cruisers; but their relatively great lengths and displacements will obviously secure superior qualities at sea as compared with the smaller cruisers, particularly in relation to maintenance of speed and steadiness of gun-platform.

The remarks made above respecting the propelling-machinery, boilers and structural arrangements of the second-class cruisers, apply also to the first class. It is proposed to sheath with wood and cover with copper the bottoms of some of these vessels, in order to fit them for service on distant stations.

To this brief description of the new cruisers may be added the following tabular statement of particulars and dimensions, chiefly based upon parliamentary papers presented during this session.

As regards the second class battle-ships, all that can be said at

Particulars.	First-class Battle Ship.	First-class Cruiser.	Second-class Cruiser.	Protected Cruisers of Pandora Class or Second-class Cruisers.	Torpedo Gunboats.
Length	380 feet	360 feet.	300 feet	265 feet	230 feet.
Breadth	75 „	60 „	43 „	41 „	27 „
Mean load draught	27 feet 6 inches	23 feet 9 inches	16 feet 6 inches	15 feet 6 inches	8 feet 3 inches.
Displacement	14,150 tons	7.350 tons	3,400 tons	2,575 tons	735 tons.
Weight of hull and fittings	4,750 „	4,040 „	1,740 „	1,255 „	320 „
H.P. forced draught	13,000	12,000	9,000	7,500	4,500
„ natural „	9,000	7,500	5,500	4,500	2,500
Speed maximum on measured mile fully laden — forced draught	17½ knots	20 knots	20 knots	19 knots	21 knots.
Speed maximum on measured mile fully laden — natural draught	16 „	18 „	18 „	16·5 „	18·75 „
Coal stowage at load-draught	900 tons=5,000 knots at 10 knots, or 1,800 to 2,000 at 16 knots	850 tons=10,000 knots at 10 knots	400 tons = 8,000 knots at 10 knots	300 tons=6,000 knots at 10 knots	100 tons = 2,500 knots at 10 knots.
Armament, excluding machine-guns and torpedoes	Four 13½-inch guns, ten 6-inch guns, and eighteen to twenty-four 6-pounder and 3-pounder quick-firing guns	Two 9·2-inch guns, ten 6-inch guns, and twelve 6-pounders	Two 6-inch guns, six 4·7-inch „, and nine 6-pounder and 3-pounder quick-firing guns	Eight 4·7 inches and eight 3-pounder quick-firing guns	Two 4·7 inches, and four 3-pounder quick-firing guns.
Protective deck—maximum thickness of steel	3 inches	5 inches	2 inches	2 inches	..

present is that they will be reproductions on a smaller scale of the first-class barbette ironclads, of which a description follows, but will not be so heavily armoured, and will carry a lighter armament. They will have a displacement about two-thirds as great as the first-class ships, be at least equal to them in speed and coal-endurance, and each carry four 30-ton (breech-loading) 10-inch guns, besides a considerable number of smaller guns.

The first-class battle-ships are eight in number. Seven of these will be armed on the barbette system, and one on the turret system. They will surpass all preceding ships in the Royal Navy in displacement, speed and auxiliary armament.

Plate 9, Fig. 3, is a sectional drawing of the first-class battle-ships, showing the arrangement of armoured protection. Figs. 4 show the principal features in plan, elevation and cross section of the barbette design. Figs. 5 give similar information for the turret-ship design.

It will be convenient first to describe those features which are common to the two types.

The principal dimensions are:—

Length	380 feet.
Breadth	75 „
Displacement (about)	14,150 tons.

Speed on measured mile, fully laden.

Forced draught (about)	17½ knots.
Natural „	16 „

Coal-endurance (estimated as above described).

Speed of 10 knots (about)	5,000 knots.
„ 16 „ „	1,800 to 2,000 knots.

The armament of each ship will include:—

Four 13½-inch 67-ton guns, in two turrets or barbettes.
Ten 6-inch 5-ton guns, on broadsides.
Eighteen to twenty-four 6-pounder and 3-pounder quick firers.
Five torpedo tubes (above water).
Two „ „ (submerged).

The heavy guns are to be carried in two protected stations, and to be given large arcs of horizontal training. All four guns will be available on either broadside. Two will be available right ahead and two right astern. The portions of the upper decks lying before and abaft the armoured stations will form simple glacis over which the 67-ton guns can fire, free from obstruction, sweeping over from 120° to 130° on each side of the keel-line. The power of freely crossing the keel-line, and of bringing all the guns to bear on each broadside, is generally recognized as of the highest importance by naval gunnery officers and tacticians. But what is of no less importance is the fact that this disposition of the heavy guns enables a very numerous and powerful auxiliary armament to be mounted in the long central battery, which is to be constructed between the armoured stations.

Within and above this battery will be carried ten 6-inch 5-ton guns, and eighteen 6-pounder quick firers. Six of the 6-inch guns will be mounted on the upper deck and four on the main deck. As regards shields and special protection for guns and gun crews, the arrangements contemplated for the battle-ships are of a character similar to those mentioned above for the first-class cruisers. Two of the upper deck 6-inch guns will be capable of firing right ahead, and two others right astern. The broadside 6-inch guns will train through 120°, 60° before and abaft the beam. All these guns are to be so mounted that they can be worked with perfect independence, not interfering with each other or being interfered with by the fire of the heavy guns. The 6-inch 5-ton guns are to be of the quick-firing pattern, if the experimental guns now under trial prove successful. The weight assigned to each of these guns with its ammunition and mounting is twice as great as would be assigned to a gun of the same calibre, but not of the quick-firing pattern. It is anticipated that the 6-inch quick-firing guns will be capable of piercing 15 inches of wrought-iron at the muzzle, and that a maximum rate of firing of about eight rounds per minute will be obtainable. A less rapid rate of firing will ordinarily suffice.

The great development of the auxiliary armament, which has been considered necessary in these ships, has very largely influenced the designs. The weight of the auxiliary armament in them is enormously greater than the corresponding weights which have been assigned to auxiliary armaments in any preceding ships. The total weight in the barbette ships (500 tons) is practically as great as the total weight of armament, including all guns, carried by the "Dreadnought" as re-designed in 1872, although the "Dreadnought" had a load-displacement of nearly 11,000 tons.

Moreover the provision of space, as well as weight, for the efficient working of these numerous and powerful 6-inch guns, with their great length in relation to their calibre, has necessitated the construction of the long central battery above mentioned, and largely influenced the disposition and extent of the armour on the belt.

In the heavy guns to be carried there is no advance in weight or calibre upon past practice, but rather a step backwards from the 110-ton guns mounted in the "Victoria," "Sans Pareil," and "Benbow." But in the auxiliary armament there is an enormous advance, and this involves a large increase in total weight of armament to be carried by the new ships. The 13½-inch guns will have a powder-charge weighing 630 lbs. with projectiles weighing 1,250 lbs.; and it is estimated that these projectiles will be capable of penetrating 28·2 inches of wrought-iron at 1,000 yards.

The armour protection of the hull proper includes two principal features. For two-thirds of the length at the water-line a belt of armour is to be fitted having a maximum thickness of 18 inches. This belt will extend 3 feet above the load-draught of the vessel and 5½ feet below it. Athwartship armoured bulkheads will complete the protection afforded by the belt, the armour at the ends of the belt and on the bulkheads being 14 inches thick.

The deck at the height of the top of the belt will be plated over with 3 inches of steel; and before and abaft the belt the protection of the hold-spaces will be secured by a similar steel deck, fitted a few feet under water and extending to the bow and stern.

These unarmoured portions at the ends of the ships will be subdivided into a great many water-tight compartments, some of the subdivisions being indicated on the plans in Plate 9, Figs. 4 and 5. The compartments thus formed will be made use of for the stowage of fresh water, stores, chain-cables, provisions, &c.

This subdivision and stowage of the spaces above the protective decks at the ends, which spaces are of comparatively small volume owing to the fineness of form at the extremities, ensures that if the thin sides above the protective deck should be perforated in action, and the spaces completely thrown open to the sea, there would follow only a very small change of draught or trim, and the ships should remain perfectly manageable.

At the bow the under-water deck is so constructed as to give strength to the stem for ramming. The stem itself will be formed of a strong and heavy steel casting suitably supported by internal girders or breast-hooks.

The rudder-head and steering-gear will be placed several feet under water, and under the protection of the thick steel deck at the after end, as is customary in all battle-ships and protected cruisers.

Above the thick-armour belt amidships there will be constructed a lightly-armoured citadel rising to a height of about 9½ feet above water. This citadel will be protected by 5-inch steel armour extending over 145 feet of the length of the side. Oblique armoured bulkheads or screens will be built, extending from the ends of this side plating to the armour on the redoubts containing the heavy guns, so that the extreme length of the citadel enclosed will be about 170 feet, or nearly one-half the length of the ship.

This defence is reinforced by means of coal-bunkers having an athwartship thickness of 10½ feet, and extending throughout the length of the citadel. The minimum defence, therefore, from the top of the belt to the height of the main deck (9½ feet above water) consists of 5 inches of steel, which is proof against all the smaller natures of quick-firing guns, and against many of the most destructive forms of attack from much larger guns. When coal is present in the bunkers this defence will be greatly increased, coal having been proved by numerous experiments to be a most valuable protection against shell fire, including shells charged with high explosives. About 500 tons of coal, equivalent to 10 inches of draught, will fill these bunkers, and, as explained below, this weight is less than the "Board margin" of unappropriated weight provided in the design.

The maximum power to be developed under measured-mile conditions, with everything at its best—good coal, skilled stokers, clean bottom, and smooth water—with forced draught, is 13,000 HP. It is contemplated that this performance should only be continued for about four or five hours, and the corresponding speed is estimated at 17½ knots. With natural draught, and under measured-mile conditions, the HP. to be developed is 9,000 and the corresponding speed 16 knots per hour.

These speeds are higher than those of any first-class battle-ships previously built for the Royal Navy, and are also higher than those of nearly all foreign battle-ships built or building.

In estimating the speeds regard has been had, as is usual in Admiralty practice, not merely to the recorded performances of other steam-ships, but to model experiments, which are conducted in the Admiralty Experimental Works at Haslar by Mr. R. E. Froude. There is nothing novel or experimental in the propelling-apparatus, and, with such excellent means of estimating the speeds as exist, there is no doubt but that anticipations will be realized. The propelling-machinery will consist of two sets of triple-expansion engines of the inverted vertical-cylinder type, driving twin-screws.

The arrangements of engines and boilers will be practically identical with those which have given such great satisfaction in the latest armour-clads which have been tried, viz., the "Victoria" and "Sans Pareil." There will be two separate engine-rooms and four distinct stoke-holds.

A large number of auxiliary engines will be fitted in these ships for working the cables, steering, ventilation, pumping, lifting boats and heavy weights, supplying electric search-lights and internal lights, working the hydraulic apparatus for the heavy guns, compressing air for torpedoes, and other services. In these respects what has now become the established practice of the Royal Navy will be followed, the tendency in recent years having been to multiply mechanical appliances and reduce manual labour.

The weight of coal intended to be carried ordinarily and at the load-draught is 900 tons. Bunker-space will be provided, however, for a larger quantity. It is estimated that at a speed of 10 knots the 900 tons ordinarily carried will, with the triple-expansion engines, and everything at its best, give a coal-endurance of 5,000 knots, which is in excess of the endurance of nearly all foreign armour-clads and most of the earlier battle-ships of the Royal Navy, which depend upon steam alone for propulsion.

Actual service with these earlier ships during the last fifteen years has shown that the coal-supply of 900 tons in the new ships will be ample for all ordinary requirements; and it can be increased when required by filling up bunkers and immersing the ships a few extra inches when leaving port.

As the matter has been mentioned specifically in the discussion on Sir Nathaniel Barnaby's Paper, it may be well to add that, in the design of all the ships included in the new programme, provision has been made for an unappropriated weight of about 4 per cent. of the displacement to be carried on the designed load-draught and at the full speed. This is known as the "Board margin," the present Board of Admiralty having laid down the condition that such provision should be made in order that, if thought desirable during construction, additions might be made to hull, equipment or armament, without involving an excess of draught.

In the first-class battle-ships this Board margin exceeds 500 tons; and if the vessels are built as designed, and no demand is made upon the Board margin, the unappropriated weight could of course be devoted to an enlargement of the coal-supply, in which case it would be made 1,400 tons and would give a coal-endurance at 10 knots of about 8,000 knots. Or should it be preferred not to increase the coal-supply, then the ships would float at a lighter draught of about 9 inches and gain a little in speed from the decrease in load.

In all the published statements respecting the ships, however, 5,000 knots at 10 knots an hour is taken as the estimated coal-endurance, and is regarded as sufficient by the Board of Admiralty.

In structure and subdivision of the hold, the vessels will resemble in all important features the battle-ships which have preceded them.

Mild steel will be the material used for the hull proper and for the protective deck plating. The thick armour on the belts, redoubts, and turrets will probably be steel-faced iron. The total load of armour and backing, including protective decks carried by each ship, will be about 4,550 tons. The total weight of armament will exceed 1,400 tons. Provisions, stores, and general equipment, propelling and auxiliary machinery, coals, &c., and Board margin make up an aggregate of about 3,400 tons. The total load to be carried by the hull proper is therefore about 9,400 tons, and the weight of structure and fittings will be about 4,750 tons, or as nearly as possible one third of the total displacement of the ships.

On the basis of past experience it may be confidently anticipated that, with the structural arrangements contemplated, ample strength will be secured for carrying these enormous loads on the relatively light hulls at the high speeds intended and under all conditions of service at sea, as well as the necessary local strength required to meet the great forces of recoil and concussion when the heavy guns are fired.

These facts can hardly fail to be of interest to the members of this Institution, by whom they can be duly appreciated as evidences of the present condition of ship-construction.

In conclusion, attention may be drawn to the principal differences between the turret and barbette designs for the battle-ships.

They are as follow :—

In the barbette ships the free-board at the ends is about 18 feet, and the heavy guns are carried 23 feet above water.

Each pair of guns is contained in an armoured redoubt or barbette tower, extending from the protective deck at the top of the belt to a few feet above the upper deck.

A revolving turn-table, placed within the armoured tower, carries the guns and gives them their horizontal movement or training. The upper surface of this turn-table is covered by strong steel plating, and the guns, in elevation and depression, move through openings cut in this protective plating.

Each gun is carried on a pair of front-pivoted slides, and the whole of the operations of training, elevating, and loading are to be performed by hydraulic power on the system devised by Sir W. G. Armstrong, Mitchell & Co., and adopted on board all the most recent British battle-ships.

When the gun is to be loaded the breech is lowered into the well or opening cut into the turn-table for the purpose, and all the operations proceed under cover of the thick armour. After the gun has been loaded and the breech closed, the gun muzzle is depressed, and the gun brought above the armoured wall into the position shown on the diagrams, Plate 9, Figs. 4.

In this fighting position the whole length of the gun is exposed above the barbette armour. All the apparatus for working the guns, and the stations at which the captains of the guns stand are, however, placed under cover of armour, and are as well protected as they could be in a turret.

Plate 9, Figs. 5, show the corresponding features for the turret-ship, where the pairs of heavy guns are carried in two armoured turrets—carried by and revolving with turn-tables (or turret bases) situated within fixed armoured redoubts. It will be seen that each gun has about one-half its length (towards the breech) protected by the thick armour of the revolving turret; but the other half (towards the chase) is constantly exposed.

After the most careful comparison and consideration of the two systems, the Board of Admiralty decided that, as the Royal Navy already contained a large number of powerful turret-ships of moderate free-board, with their guns placed at a moderate height above water, it was desirable that seven of the new first-class battle-ships should be built on the barbette system. By dispensing with the protection of the breech end of the gun it is made possible to place the guns themselves 6 feet higher above water than in the turret-ship, and to have a high free-board at the extremities.

A greater power of maintaining high speed at sea, and fighting the guns in bad weather, is thus secured for the barbette ships than is possible with the moderate free-board at the ends and less height of guns above water in the turret-ship.

The following comparison between the first sea-going ironclad of the Royal Navy (the "Warrior"), laid down in 1859, and the new battle-ships about to be constructed, can hardly fail to be of interest:—

——	"Warrior."	New Battle-ships.
Length between perpendiculars . . .	380 feet.	380 feet.
Breadth, extreme	58¼ „	75 „
Mean load-draught	26 feet 9 inches.	27 feet 6 inches.
Displacement	9,210 tons.	14,150 tons.
Measured-mile speed, maximum . . .	14·1 knots.	17·5 knots.
Maximum HP. on measured mile . .	5,500	13,000
Coal carried	700 tons.	900 tons.
Coal endurance at 10 knots	about 1,800 knots.	5,000 knots.
Maximum thickness of armour . . .	4½ inches.	18 inches.
Total weight of armour and backing on sides, deck, &c.	1,370 tons.	4,550 tons.
Total weight of armament	570 „	1,420 „
„ „ equipment	820 „	1,430 „
„ „ propelling-apparatus and auxiliary machinery	980 „	1,100 „
Total weight of hull and fittings . .	4,760 „	4,750 „

The Paper is accompanied by several diagrams, from which Plate 9 has been engraved.

OBITUARY.

GEORGE HENRY BAYLY, the youngest son of John William Bayly, of Tolka Lodge, Finglas, County of Dublin, was born on the 7th of June, 1834. He was educated at Nutgrove School, Dublin, and went to America in 1849 to join his brother, Mr. William Cole Bayly, on the York and Harrisburg and Manasses Gap Railroads, for two years, and then entered the locomotive works of Messrs. Smith and Perkins, Alexandria, Virginia, where he remained three years, and when Mr. Perkins took charge of the Central Ohio Railroad Mr. Bayly went with him to Ohio until 1859. In the latter year he returned to England, and was appointed Assistant Engineer on the Bombay and Baroda Railway, where his previous experience in the erection of timber and iron bridges made him a valuable assistant in connection with the large structures over the Nerbudda, Mindola, and Veturnee rivers, also the Bassein Creek. He was then appointed to take charge of the erection of the locomotive and machine shops at Parell, Bombay, which he designed and finished under the late Chief Engineer, Mr. Francis Mathew. During this time he erected also the railway stations and other works at Bombay, and was sent on special duty to the Demaungunga and Parna rivers, when the bridges over those rivers were washed away. He restored the line for traffic in a short time by erecting piers made of sleepers and filled in with stone. He resigned his position as Resident Engineer in 1877 to take the contract for the erection of the new Nerbudda Bridge in connection with the late Mr. Thomas White. This bridge, designed by Sir John Hawkshaw, Past President Inst. C.E., consisted of twenty-five spans, of 187 feet 6 inches each, with depth of foundations 55 to 104 feet, and 75 to 105 feet below low-water, believed to be the deepest foundations up to that time of any known bridge, a weight of 320 tons having been put on one column to get it to the required depth. This bridge was completed in 1881, within three and a half years of its commencement, and for £40,000 less than the previously contemplated English contract. After a short sojourn in England Mr. Bayly was connected with the railway from Goa to Dharwa for a short time with Sir Thomas Thompson, Bart., and Mr. T. A. Bulkley.

In 1886, as contractor, he commenced the erection of the superstructure of the Kalpi Jumna Bridge, Indian Midland Railway, ten spans of 250 feet each, which he executed in eight months. In 1887 he took the erection of the superstructures of the two Betwa Bridges, thirteen spans of 150 feet each, and 80 feet above low-water, and nine spans of 150 feet each, 50 to 80 feet above low-water. These he finished before the monsoon of 1888, when his health obliged him to return to England. Fearing the winter in this country, he left Ireland for America in October, proceeding thence, *viâ* San Francisco, to New Zealand. When he arrived in January 1889, after several excursions round the island, he was taken suddenly ill, and died at Christchurch of congestion of the lungs, on the 2nd of April, 1889, after engaging his passage for England. By his death the profession has lost an eminent though silent member, who possessed great talent for the construction with native labour of large bridge works.

He was elected a Member of the Institution on the 14th of May, 1872.

WILLIAM BROWN CLEGRAM, whose death occurred on the 3rd of June, 1889, was born on the 1st of October, 1809, at Shoreham, Sussex, where his father, who began life as a sailor, had settled in order to take charge of improvement works designed by him for the harbour at that place. The elder Clegram had frequently visited that port as shipmaster, and was the successful candidate for the premium offered by the authorities for a design that would fix the harbour mouth, which up to that period was constantly shifting, owing to the movement of the shingle. His methodical and practical observation of the local conditions led him to compete, and was the cause of his succeeding, in a race for which he had not been specially trained. From this time he adopted the profession of engineering, and took charge of the works which he had designed. The subject of this notice was brought up by his father to the profession, and before he quitted Shoreham in 1827 had assisted him in his drawings and surveys. At this time Mr. Clegram, senior, was selected to take charge, under Mr. Telford, Past President Inst. C.E., of the Gloucester and Berkeley ship-canal, then not yet completed. His son almost at once took service in the same concern, being appointed Clerk in 1829. Whilst holding this office he had leisure for assisting his father in designing new basins, quays, graving-docks, and other works at Gloucester; and in 1861 he succeeded to the post of

Engineer and Superintendent. At this time the important and practically untried system of towing by means of screw steam-tugs was introduced on this canal, and formed the subject of a Paper, "Results of the Employment of Steam-Power in Towing Vessels on the Gloucester and Berkeley Canal."[1]

Mr. Clegram was always an ardent advocate for the retention and improvement of the water-ways of the country, and had more than once to sink personal feelings as well as capital in their defence and advancement.

In conjunction with the late Mr. T. E. Harrison, Past President Inst. C.E., he carried out important improvements at the sea entrance to the canal at Sharpness, the position of which was the subject of long and mature deliberation, rendered none the easier by the consideration that it was necessary to provide access for vessels of some 3,000 tons displacement in a tide-way where the tide frequently set at the rate of 7 knots an hour. That these works proved equal to the requirements of the trade of the district, for fifteen years, is evidence of his sound judgment and power of acquiring technical knowledge from others; and that they can scarcely be said now to be on this footing is due to the fact that Mr. Clegram had to make the most of the funds, provided in a great measure by his untiring activity, in a district not specially favoured with a redundant or too vigorous population. The works consisted of open wooden piers on either side of the entrance into a tidal-basin with lock, floating-basin, graving-dock, and connecting-cut to the old works. He was also one of the prime movers in the founding of the Severn Bridge. Perhaps the chief noticeable features of his character were the wide range of his attainments, and the thoroughness with which he was wont to grasp every detail of the work that he set himself to carry through. He was a good artist, a keen observer of nature, at home with both microscope and telescope, a great reader, and an accomplished musician. To all about him he was ever considerate and courteous, with a kind word for every one with whom he came in contact. His advice was at all times eagerly sought by his more intimate friends, and his judgment relied upon as sound and trustworthy. He was, like his father, a systematic recorder of daily events, small and great, which included meteorological observations.

He was associated in early life with the Brunels, father and son, and with Admiral (then Captain) Beechey, during his important work of surveying the Estuary of the River Severn, and officially with the late Mr. Telford, Mr. James Walker, and Sir William Cubitt, the latter having been his proposer at the Institution.

---

[1] Minutes of Proceedings Inst. C E., vol. xxvi. p. 1.

He was elected a Member of the Institution on the 3rd of April, 1849.

JAMES FARRAR was born at Walmersley, near Bury, on the 20th of November, 1825. He was for some time, at the commencement of his career, in the office of Mr. Whitehead, a local solicitor of repute, and afterwards with Mr. Harper, solicitor, also of Bury. He ultimately determined to follow the profession of a surveyor and civil engineer, and was for some time engaged upon local works of minor importance. Later he became an assistant to Mr. (now Sir Robert) Rawlinson, K.C.B., Vice President Inst. C.E. In 1863 he was appointed Borough Surveyor of Bury, which post he retained until the incorporation of the borough in 1876. During his tenure of office, he carried out many important sanitary works, including, a system of main drainage, the purchase of land and the construction of a town's yard where the whole municipal work was centralized. In the period of depression following the cotton famine, he designed and carried out as a relief work the present Bury Cemetery, which, laid out in a most tasteful manner, forms one of the most conspicuous works in the district. Quickly acquiring a reputation for skill, he was soon engaged upon most of the Parliamentary fights for Water and Railway Bills in Lancashire and Yorkshire, chief amongst these being the Sheffield, Bury, Wakefield, Southport, and Haslingden Water Schemes.

Meanwhile he was consulted by most of the newly-formed local authorities in the neighbourhood of Bury as to the sanitary requirements of their districts, and was ultimately appointed Engineering Adviser to the Radcliffe, Whitefield, Heywood, Little Lever, and Dwygyfylchi Local Boards, and to the Rural Sanitary Authorities of Conway and Bury, and many other towns, preparing and carrying out drainage and other schemes. He was scarcely less sought after for advice on water-supply, and was actively engaged upon the construction of some portions of the Bury and Radcliffe Water Company's Works, the Haslingden and Rawtenstall Water-works Company's Reservoir, two companies which ultimately united. He also enlarged and remodelled the water-supply to the town of Conway and other places on the Welsh coast. He acquired a high reputation as a valuer of land and property, and was engaged upon most of the large transfers of property which took place in the district, especially in the determination by arbitration of the amount of compensation to be paid by authorities compulsorily acquiring land under Act of Parliament. He held the appointment of Valuer to the Bury Union Assessment-Committee, and was frequently called upon to give evidence in cases of railway, water-works, and other assessments, not only for the authority by whom he was retained, but for other authorities in the county. The last work upon which he was engaged was the construction of the Todmorden Water-works, which consisted of a storage-reservoir with a capacity of 100,000,000 gallons, and the conveyance and distribution of the water in the town and district, the latter part of the scheme being a most tedious and difficult work, owing to the intersections of the roads by culverts, bridges, pipes, and old works of all descriptions. The cost of the undertaking will be £50,000.

Mr. Farrar had for some time been in failing health, the exposure and work of his early career having told upon him. After being confined to his bed for a period of nine weeks, he died of Bright's disease and dropsy on the 18th of April, 1889.

He was elected an Associate of the Institution on the 11th of May, 1869, and transferred Member on the 7th of January, 1879. He was a Fellow of the Surveyors' Institution, a Justice of the Peace for the Borough of Bury, and a Director of the Southport Water-works Company, and of the Manchester and Liverpool District Banking Company.

SIR CHARLES LANYON, who, after a protracted illness, passed away at his residence, The Abbey, Whiteabbey, on the 31st of May, 1889, was a prominent figure not only in Belfast and the County of Antrim, but throughout the whole of Ireland, having been professionally employed in every county with the exception of one. He was the son of Mr. John Jenkinson Lanyon, of Eastbourne, Sussex, and was born on the 6th of January, 1813.

He was articled to the late Mr. Jacob Owen of the Board of Works, Ireland, one of whose daughters he afterwards married. In the year 1835, at the first examination for County Surveyors, he took the second place on the list and was appointed to the County of Kildare; but the following year he was transferred at his own request to the County of Antrim where a vacancy had occurred. Mr. Lanyon discharged the arduous duties of his office with extraordinary zeal, energy and tact, and was the means of getting many of the most important county works, such as the Antrim coast road from Larne to Portrush, carried into execution.

The general management of the repairs and maintenance of the roads and bridges was carefully attended to, and after some years it was generally admitted that in these respects Antrim was the premier county in Ireland.

When County Surveyor he designed and carried out the Queen's and Ormean Bridges over the River Lagan at Belfast, and the Agivy Bridge over the Lower Bann. Besides his strictly county work, he was the Chief Engineer for the group of railways once known as the Belfast and Ballymena, and the extensions thereof to Portrush and Cookstown, now amalgamated with the line from Coleraine to Derry, under the title of the Northern Counties Railway. He was also Engineer to the Belfast, Holywood and Bangor, and the Carrickfergus and Larne Railways. In conjunction with Mr. Bateman, Past President Inst. C.E., he carried out that part of the Belfast Water-works known as the Woodburn scheme, a considerable work in its day.

Whilst far from neglecting his engineering and official duties, Mr. Lanyon was so fortunate as to acquire a very extensive architectural practice. Many of the residences of the county families, not only in Antrim but throughout Ireland, were either built or remodelled under his directions. In Belfast his most notable edifices, for local purposes, are the County Gaol, and County Courthouse, which are connected with one another by an arched passage under the Crumlin Road. There are many other proofs of his skill, but the Custom House, the Queen's College, the Presbyterian College, and the Deaf and Dumb Institution, are the best known and most likely to be associated with his memory. As Honorary Architect to the Church Extension Society some fourteen churches were erected in the Diocese of Down, and Connor, and Dromore, from his designs.

In October, 1866, Mr. Lanyon was returned in the conservative interest as one of the members for Belfast. In 1868 he received the honour of knighthood in recognition of his high professional position.

Sir Charles Lanyon was for a lengthened period an energetic and very useful member of the County Antrim Grand Jury, and in 1878 held the office of High Sheriff of the County. For a great many years he was a Justice of the Peace for both the County of Antrim and the City of Belfast, he was also a deputy-lieutenant of the County Antrim. He was an enthusiastic member of the Masonic fraternity, and for a long time occupied the position of Grand Master of the Province of Antrim. He was elected a Member of the Institution on the 24th of March 1840.

He was for some time a Vice President of the Royal Institute of British Architects, and President of the Institution of Civil Engineers of Ireland. He also filled for several years the office of President of the Royal Institute of Architects in Ireland, was a Royal Hibernian Academician, a member of the Belfast Corporation, and in the year 1862 served the office of Mayor.

Sir Charles Lanyon was a general favourite and a most excellent man of business; he was perfectly courteous and gentle, but at the same time firm and determined, and his aim was to have his works properly carried out. This characteristic was very marked during his occupancy of the office of County Surveyor.

Sir Charles was for a lengthened period Vice Chairman of the Belfast and Northern Counties Railway, and Chairman of the Belfast, Holywood, and Bangor Railway, and also occupied a seat on most of the County and City Boards, such as the Prisons Board, the Lunatic Asylum Board, the Local Marine, the Government School of Art, of which he was President, the Belfast Harbour Board, the Deaf and Dumb Institution, Poor Law Board, the Sailors Home, and the Nurses Home.

HENRY PEVERIL LE MESURIER, eldest son of Mr. Benjamin Le Mesurier, of Wallington, Berks, and St. Martin's, Guernsey, was born at Alderney on the 4th of November, 1828. He was educated at the private school of the Rev. Philip Hayes, and subsequently at the well-known Elizabeth College. In 1846 he was articled for five years to Mr. R. B. Grantham, and on the expiration of his pupilage went to Alderney as engineering assistant to Messrs. Jackson and Bean, the contractors for the breakwater and forts then under construction by the British Government. Here he came into intimate contact with the officers of the Royal Engineers in charge of the works of defence, and gained much varied experience which stood him in good stead during the rough experience of after-life.

In 1853 Mr. Le Mesurier was appointed an Assistant Engineer on the East Indian Railway, and left for Calcutta in December of that year, with a large party of engineers, under Mr. Edward Purser, and from February 1854 to November 1856 worked on the surveys and construction between Benares and Cawnpore. In September 1854 he was promoted to the position of Resident Engineer. He ran the traverse of the original line between Futtehpore and Cawnpore, and set out the centre line from Mogul

Serai to Allahabad station, including the site of the present bridge over the Jumna at Allahabad. In November 1856, the work of construction being in a forward state on the length between Mogul Serai and the River Tonse, Mr. Le Mesurier was sent to the Punjab to examine the River Sutlej, with a view to selecting a site for a railway-bridge. A few months later the Mutiny broke out, and he had the opportunity, which is said to come to most men once in their lives, of showing the stuff he was made of. The way in which he met the call is best recorded in the words of Sir Donald Macleod, Lieutenant-Governor of the Punjab, who was at the time Financial Commissioner at Lahore, and who subsequently, in 1870, made strong representations to Lord Lawrence's Government for some recognition of Mr. Le Mesurier's services. Sir Donald says:—

"After the news of the outbreak at Meerut had reached us by telegram, Ferozepore was the first station in the Punjab in which excitement made itself apparent among our native soldiery, and a report was then circulated that the native troops at Lahore and Mean Mir had broken out, and had reached the Sutlej, in order to co-operate with their brethren at Ferozepore.

"The precaution of disarming those troops had most fortunately been adopted with the utmost promptitude at Mean Mir, so that the intention which they were thus shown to have entertained was frustrated. But, nevertheless, things speedily began to assume an alarming aspect, and the existence of a large magazine, well stored with powder, rendered the position a most critical one. The Brigadier commanding was quite new to the charge, having arrived only two days before, and there was no Executive Engineer of Government on the spot.

"Under these circumstances, Mr. Le Mesurier, who was at the time in the interior, hurried in *proprio motû* to Ferozepore, and placed his services at the disposal of the Brigadier commanding, who most gladly accepted them, and obtained sanction to his being nominated Executive Engineer, which was duly gazetted. Mr. Le Mesurier at once set vigorously about completing the defence of the magazine, which in a short time he effected in a satisfactory manner. But as the arsenal contained upwards of 700,000 lbs. of gunpowder, packed away in store-rooms, where an ingenious incendiary might at any time succeed in destroying the whole, it became a matter of the very first importance to have this placed out of immediate danger, and accordingly to this matter he at once directed his special attention.

"The whole of the native establishment attached to the magazine speedily became more or less suspected, and several of them were not long afterwards hanged for treason and mutiny. But, nevertheless, Mr. Le Mesurier made use of the principal of these men as his instruments for getting the work carried out, European guards being at hand to act against them if any mutinous disposition should be exhibited. A lucifer match or a burning-glass would have disposed of the whole of the powder and of the European guard.

"The whole of the gunpowder was in a short time taken out of the store-rooms, and buried deeply and securely in the earth, the operation being carried out with so much judgment and skill that when, not long afterwards (two months), the gunpowder was dug up to be served out to the siege-train proceeding to Delhi, not a single barrel was found damaged."

General Peter Innes, the Brigadier commanding at Ferozepore, under whom this service was performed, in supporting Sir Donald Macleod's memorandum, says:—

> "On coming in I at once employed him (as Brigadier Commanding) to put under ground (7,500) seven thousand five hundred barrels of gunpowder, the only powder between Calcutta and Kurrachee. The powder was in condemned mud buildings, and a shot fired in would have blown all up.
>
> "The Punjab Government wrote to me to say that if this powder was lost India was lost. . . . On the 19th August, when a portion of the 10th Cavalry broke and bolted, he was the only European gentleman present, and assisted a part of the 61st Foot in driving the rebels from the guns they had possessed themselves of.
>
> "I have no hesitation in saying Mr. Le Mesurier is deserving of every reward the Government are pleased to bestow for his very valuable services during the year 1857."

But the mills of Government grind slowly, and it was not till nearly twenty years later that his services were recognized by his being made a Commander of the Star of India.

Mr. Le Mesurier could at this time (September and October 1857) get no orders from the Chief Engineer of the railway at Allahabad, and it would have been unsafe to return to field-work on the Sutlej River in the plains. He therefore left Ferozepore, and proceeded to Simla, *viâ* Loodiana and Kalka, to obtain information connected with the supply of timber and building-materials for railway purposes. During this part of his career there occurred an incident that illustrates the resourcefulness of Anglo-Indians during that period of mortal peril. In company with Lieutenant William Wells Lee, of the Bengal Army, and Lieutenant Crane, of H.M. 32nd Regiment, Mr. Le Mesurier was visiting the Rajah of Busahir, at his capital, Rampore, on the Sutlej. There were some men of doubtful loyalty at Busahir, and it was ascertained that there was also a store of gunpowder in the magazine. Under these circumstances, Mr. Le Mesurier and his associates obtained permission from the Rajah to fire from his one field-piece a royal salute in his honour. Having thus obtained access to his store, they fired away until all his powder was burnt!

Mr. Le Mesurier returned to Ferozepore at the end of 1857, and then marched to Delhi, where he remained until he could get a safe run through to Cawnpore, and so down to Allahabad. Here he found the railway offices established inside an intrenched camp, and Mr. Edward Purser, the Chief Engineer, and numerous members of the staff living at an old house, formerly Berrill's hotel, on the Jumna bank. Mr. Le Mesurier remained with Mr. Purser until September 1858, when he proceeded to organize a staff for the survey of the proposed line from Allahabad to Jubbulpore. In the beginning of the cold season of 1859, being then only thirty years of age, he was confirmed in the appointment of Chief Engineer of the Jubbulpore line, East Indian Railway. Soon after this, being in ill health, Mr. Le Mesurier came to England. He soon recovered, and, it being found that he could work advantageously at home on the plans of the Jubbulpore line, he took a temporary office in Manchester Buildings, Westminster, which he retained till late in 1862. In July 1863 he returned to India and continued to act as Chief Engineer of the Jubbulpore line until five years later. He then passed to the service of the Government of India, for whom he took charge, as Chief Engineer, of the surveys of the railway from Lahore to Rawal Pindee; but a few months later he resigned his appointment, having been invited, in September 1868, to join the staff of the Great Indian Peninsula Railway, as Chief Engineer of the Presidency Division. In the following May, Mr. Le Mesurier was appointed Acting Agent of the Great Indian Peninsula line, and in October of the same year he was confirmed as Agent, and continued to hold that position until February 1877. In January of that year Mr. Le Mesurier had received the offer of an appointment as Member of the Board of Administration of Egyptian Railways, Telegraph, and Port of Alexandria, of which Board General Marriott, C.S.I., was President. This offer he accepted, and on the death of General Marriott, in December 1879, was appointed the latter's successor.

In this responsible post he discharged his duties efficiently and well, though for a second time exposed to the dangers of rebellion and the horrors of massacre, from which his wife had a narrow escape. He received the English war medal and the Egyptian bronze star, also a letter of thanks from Lord Granville; in addition to which H.H. the Khedive was pleased to confer on him the collar and the second class of the Osmanieh.

That continued and exceptional strain, physical and mental, should result in a constitutional break-down is what might have been expected. Mr. Le Mesurier himself resisted many warnings, such was his sense of public duty and determination to accomplish the work he was appointed to do. Yielding to the advice of friends, in 1887 he visited Guernsey, with a view of recruiting his health by native air and rest. Whilst there an attack of paralysis rendered his return to official life impossible. From this illness he imperfectly recovered. Great constitutional debility, followed by a second attack on the 30th of July, 1889, closed an honoured and useful life, to the intense sorrow of his family and friends.

Mr. Le Mesurier was elected a Member of the Institution on the 21st of February, 1862.

FREDERICK LESLIE, son of Mr. John Leslie, the inventor of the tubulated gas-burner, and a brother of Mr. Henry Leslie, well known in the musical world, was born in the year 1828. He studied in the Applied Sciences Department of King's College, London, with a view to entering the profession of gas engineering, and then served a pupilage to the Engineer of the Equitable Gas Company. He was next, for four years and a half, at the works of the Bristol United Gas-light Company, having charge of one of the stations as assistant to the engineer. He was also concerned in the reconstruction of the works, including the erection of two large tanks, gas-holders, gas-governors, steam-engines, &c. He afterwards accepted an engagement as gas engineer to the Corporation of Stockport, where he remained for four years, and for one year as Chief Engineer of the Crystal Palace District Gas Company. Early in 1866 Mr. Leslie was appointed Chief Engineer to the City of Moscow Gas Company, and thereafter his career was mainly confined to Russia. The Moscow company was an English enterprise, and Mr. Leslie was appointed to superintend the erection of the extensive works, plant and machinery, and the piping of the city. Mr. Leslie exhibited great skill and ability in coping with the difficulties which from time to time cropped up, especially those of manufacture and distribution, caused by the extreme severity of the climate during six months of winter, when the thermometer sometimes registers – 60° Fahrenheit. One autumn, during the period of Mr. Leslie's management, a large wooden bridge over the River Msta, on the Nicholas Railway, then forming the only railway between Moscow and the port of St. Petersburg, was destroyed by fire. Only a very small portion of the annual coal-supply had been trucked from St. Petersburg, and no more could be obtained, the coal-fields of South Russia not having then been opened up. The stock of coal at the gas-works became exhausted, whereupon Mr. Leslie, as a temporary measure, at once adapted the plant originally designed for distilling coal for the manufacture of gas, and for many months successfully lighted the city with gas made from wood. Silver birch was the principal material; but, in fact, any other substance which could be practically employed was used, petroleum and petroleum refuse being used as an enriching material. As an administrator Mr. Leslie was minutely careful and accurate, and it is solely due to his ability, energy, tact and judgment, that the City of Moscow Gas Company was able to tide over the first years of its existence, and that the property at Moscow was extricated from the perilous position in which the onerous conditions of the Company's concession had placed it. In 1881 the enterprise, which had then become the Moscow Metropolitan Gas Company, was sold to a French Company, and Mr. Leslie returned to England. He embarked in a private business relating to heating, ventilating, and sanitary matters, but after a few years relinquished it with heavy loss. He then invented a system of ventilation which was adopted in one or more of the London theatres, and also introduced some considerable improvements in the tubular gas-burner first devised by his father. He was engaged in working these patents when he died, on the 20th of February, 1889.

Mr Leslie was a strict disciplinarian, but he was always kind, just and considerate to those about him and under his command. For these characteristics his name was almost proverbial in both the old and the new Russian capitals, and he was respected alike by his friends and his adversaries, including some of the most highly and influentially placed in the administrative circles of the Russian Empire. In July 1873 he was appointed British Vice Consul at Moscow (unpaid), and retained the appointment until he left the country in July 1881, acting under Her Majesty's Consul at St. Petersburg.

Mr. Leslie was elected an Associate of the Institution on the 3rd of May, 1864, and was transferred to the class of Members on the 17th of December, 1866.

THE HONOURABLE HENRY HAWORTH LESLIE, who was born on the 19th of April, 1845, at Kenton, Devonshire, was the third son of Captain Martin E. Haworth Leslie (late 60th Rifles) and the Countess of Rothes. He assumed the surname of Leslie in 1886, on his mother's succession in her own right to the Earldom of Rothes. Educated at Charterhouse, he was apprenticed in 1863 to the late Mr. Robert C. May, of Westminster. During his articles he studied his profession at workshops in Birmingham and Middlesbrough, and was placed in charge of the construction of the gas-works at Ashford, in Kent. In 1867 Mr. Haworth was engaged by Messrs. Barkley Brothers on the Bucarest and Guirgevo Railway, and was employed by them during the whole time of construction until 1869. In 1870 he went out for Messrs. Waring Brothers and McCandlish to the Honduras Railway. Here he was employed on difficult undertakings involving much hardship and dealings with people badly disposed to the railway. On the suspension of the works in 1871, he returned to England, suffering from intermittent fever contracted in Honduras. Mr. Haworth was appointed an Assistant Engineer on the Madras Railway in 1873, was promoted after two years' service, and in 1881 received pay and allowances as first class Engineer. During the time of his work in India, he was three years in charge of the re-construction of the Cheyor Bridge, and two years in charge of the construction of the new bridge over the Pennair River, besides having had charge at one time or another of nearly every division of the railway during the worst time of the famine and floods.

Mr. Haworth Leslie returned to England in March, 1888, with his health much impaired, and died on the 15th of March 1889, in the forty-fourth year of his age, much regretted by a very large circle of friends. He was elected a Member of the Institution on the 7th of February, 1882.

CHARLES REBOUL SACRÉ was born in London on the 4th of September, 1831. At the age of fifteen he was articled to Mr. Archibald Sturrock of the Great Western Railway. After serving his time he was engaged in a responsible position upon the Great Northern Railway as Manager, first of the Boston, and afterwards of the Peterborough Works of that Company.

He next became Chief Engineer of the Manchester, Sheffield, and Lincolnshire Railway, and was besides connected with the South Yorkshire Railway, the Cheshire Lines Committee, and the Humber Conservancy, also the Manchester South Junction and Altrincham Railway. During his many years' service in these capacities, he was continually engaged as Engineer of the various new works in connection therewith, and took no mean part in giving evidence for Parliamentary Committees. His engineering ability, with his acknowledged common sense in all matters of moment, gained him a considerable reputation.

The results in respect to the working expenses of the Locomotive, Carriage and Permanent Way Department under his control showed notable success; this gained for him the good feeling of the directors and shareholders of the railway company, owing to the savings effected. Mr. Sacré retired from the Manchester, Sheffield and Lincolnshire Railway some few years ago, but was retained as the Company's Consulting Engineer, and was engaged by several other railway companies to give evidence in connection with parliamentary arbitration and other matters. His kind feeling, manner, and good judgment have been suitably acknowledged from time to time in his various positions by the testimonials that have been presented to him by his friends. He died on the 3rd of August, 1889. Mr. Sacré was elected a Member of the Institution on the 8th of January, 1867.

JAMES SIMPSON, the eldest son of the late Mr. James Simpson, Past President of the Institution of Civil Engineers, was born on the 10th of January, 1829, at Thames Bank, Chelsea, the residence of his father, who was at that time Engineer to the Chelsea Water-works Company. He was educated at St. Peter's Collegiate School, Eaton Square, and at Dr. Lord's private school at Tooting. In 1846 he was articled to Messrs. Burns and Bryce, Architects, Edinburgh, when he lived with the late Mr. John Brown, M.D. Returning to London in 1851 he joined his father, who was at that time engaged in an extensive practice as a civil engineer, and superintended for him the execution of several important works, amongst others the construction of the water-works at Carlisle and the extension of the Chelsea Water-works Company to Surbiton, Surrey. In 1857, he joined the firm of Simpson and Company, manufacturing engineers, taking a leading part in the introduction of improved pumping-plants, especially the Woolf Compound Pumping-Engines, and in the construction of water-works abroad. For the past few years failing health prevented close attention to business, although to the last he took a lively interest in all matters connected with engineering. He was much respected by those in his employ, as well as by others with whom he was associated, not only for his kindliness of disposition, but also for his readiness to impart knowledge. His health gradually failing, he died at Brighton on the 11th of May, 1889, and was buried at Brompton Cemetery. He was elected a Member of the Institution on the 6th of December, 1864.

FRANCIS CROUGHTON STILEMAN was born at Winchelsea on the 25th of May, 1824. He was the second son of Richard Stileman, of the Friars, Winchelsea, and was educated at the Rev. Dr. Lord's school. He then became a student at the College of Civil Engineers, Putney, under Lieut.-Col. Hutchinson, H.E.I.C.S., the Rev. Mr. Page, and the Rev. Mr. Cowie, now Dean of Exeter, from 1840 to 1844. On leaving Putney, he was articled to the late Mr. J. R. McClean, Past President Inst. C.E., during which time he acted as Resident Engineer on the South Staffordshire Railway, Birmingham, Dudley and Wolverhampton Railway, the Staffordshire and Worcestershire Canal Reservoirs, and the South Staffordshire Water-works. In 1849 he entered into partnership with Mr. McClean, and shortly after left Staffordshire for the Furness district, where he resided from 1850 to 1853. During this latter year he came to London, being associated with Mr. McClean as Engineer to the Furness Railway Company, Furness and Midland Railway, Tottenham and Hampstead Railway, Eastbourne Water- and Sewage-works, Ryde Pier and Tramways, Bristol and Portishead Railway, Portishead Docks, and for the system of railways in Galicia and Moldavia known as the Lemberg and Czernovitz. One of the works of the Furness Railway—the enlargement of the Lindal tunnel, originally built for a single line—was an undertaking of great interest in its day. Mr. Stileman contributed to the Minutes of Proceedings a Paper "On the Construction and Enlargement of the Lindal Tunnel on the Furness Railway," which was printed in vol. xix., p. 229. On the death of Mr. Walker, in 1862, the firm of McClean and Stileman became Consulting Engineers for the Harbours of Dover and Alderney, Plymouth Breakwater Fort, the Surrey Commercial Docks, and other works. Mr. Frank McClean then became a member of the firm, but he only continued his connection until 1869. On the retirement of Mr. McClean from active work in 1868, Mr. Stileman became Engineer-in-Chief to the Furness Railways harbour and docks, consisting of an entrance-basin, 8½ acres, with 100-feet openings and 32 feet depth of water at H.W.O.S.; a lock, with three pairs of gates 700 feet long by 100 feet wide; and dock and timber ponds of an area of some 200 acres. In addition to the Furness Railway he acted as Engineer for most of the large works in the town, carrying out among others the existing system of the Barrow Corporation Waterworks. He also designed and carried out the Keighley Water-works, Ryde and Newport Railway, Lowestoft Sewerage-works, &c. He was also engaged on many Parliamentary deposits of great importance, and was well known in the Committee Rooms as an excellent engineering witness.

Mr. Stileman was elected a Member of the Institution on the 5th of March, 1855, and in 1884 was elected to a seat on the Council, which he continued to hold till his death. He was also a Member of the Iron and Steel Institute. He occupied a position of eminence in the profession, in which he was appreciated for his uniformly upright and conscientious conduct. He died suddenly in his office on the 18th of May, 1889, aged sixty-four, having only some few hours previously given evidence in an arbitration case connected with the Manchester Ship Canal.

At the Ordinary Meeting of the Institution on the 21st of May, the President, Sir George Bruce, specially alluded to the recent death of Mr. Stileman, *ante*, p. 203.

FRANK CHARLES BLACK, the eldest son of the late Charles Christopher Black, M.A., Trinity College, Cambridge, was born in 1839, and educated at Bruce Castle School, Tottenham. His earliest employment was under Messrs. Brassey in the construction of the Maremma Railway in Italy, on which line he had charge of the Pieve Vecchia Tunnel, and of 8 miles of railway, including four bridges. In 1864 he proceeded to India and had charge for Messrs. Brassey, Wythes and Henfrey, of 20 miles of the Dehli Railway on which was the crossing over the Ganges Canal. He built this bridge, acting under Mr. J. C. Moulton. In the following February he was engaged on the laying of the Oudh and Rohilkhand Railway in the service of the Company, and a few years afterwards he made the necessary survey for the projected branch, 35 miles in length, up to the well-known hill sanitarium of Nynee Tal; but the scheme was subsequently abandoned on the score of expense. He subsequently joined the Indian Public Works Department, in which he rendered continuous service until 1882. During this time he did particularly useful work as District Engineer, the roads and buildings in the Hannipur District being kept by him in such specially good order, as to call forth the warm written praise of the Judge, Magistrate, Superintending Engineer, Deputy Commissioner, and other officials. By constant efforts, spread over a period of six years, he was unusually successful in the planting of numerous avenues of trees throughout the district, and 13 miles of these were in flourishing condition in 1880. In 1882, Mr. Black was transferred to the Archæological Department, a branch of work for which he had special taste and fondness, and a limited grant was sanctioned to enable him to take steps for the conservation of the Vittala Swami Temple, at Bijanagur, and the Alaiva, or Shore Temple, at Mahavellipore, or the Seven Pagodas, on the Coromandel coast (described in Fergusson and Burges, Cave Temples of India). From the first named he cleared away an enormous mass of jungle at a cost of Rs. 4,000, and at the Alaiva Temple the work consisted mainly in the excavation of the ornamental walls which were buried in sand, leading to the discovery of some interesting inscriptions previously unknown. His last archæological work appears to have been in connection with the restoration of part of the Stupa of Amravati in 1884, after which the funds necessary for the conservation of the ancient monuments of Southern India, a matter strongly commended at various times to the notice of the Government by the highest authorities in England, were withdrawn. At the time of Mr. Black's sudden death on the 29th of May, 1889, he was occupying the post of Local Funds Engineer at Ellore. His numerous written testimonials from officials of high grade speak of his professional knowledge as much above the average, while his activity as a rider and walker is often mentioned. He is also stated to have been very successful in gaining the respect and affection of his subordinates.

Mr. Black was elected an Associate Member of the Institution on the 2nd of February, 1875.

WILLIAM ARTHUR FREND was born in County Limerick, Ireland, on the 22nd of April, 1858. He was educated at the Limerick Collegiate Academy under Mr. James Weir, and afterwards entered Trinity College, Dublin. Here he took the degrees of Bachelor of Arts and Bachelor in Engineering, and at the examination for the latter took special certificates in engineering and physics. On leaving college he joined the staff of Messrs. Falkiner and Stanford, and was by them employed on the Rathmines Waterworks, near Dublin. He then entered the service of the Board of Public Works, Ireland, and was appointed to the charge of a pier being built at Rosscarbery, County Cork. This work, which occupied three years, was brought to a successful issue early in 1888; and in the autumn of the same year Mr. Frend emigrated to Rosario de Santa Fé, Argentine Republic. Here he was appointed Assistant Engineer on the Central Argentine Railway, and for the space of about six months filled the position with credit to himself and to the entire satisfaction of his employers. Unhappily, he was stricken with typhoid fever, and on the 13th of March, 1889, succumbed to the disease. As a son, a brother, and a friend, he had few equals. In his business relations he gained the respect of all those with whom he came in contact, and would no doubt have made his mark in the profession had his life been spared.

Mr. Frend was elected an Associate Member of the Institution on the 24th of May, 1887.

SAMUEL PETTY LEATHER, son of Mr. John Leather, an architect and surveyor, was born at Sheffield on the 8th of April, 1821. At the age of sixteen he was taken in hand by his grandfather, and was apprenticed to Messrs. Maclea and March, engineers and machine-makers, of Leeds, working for five years according to the ordinary practice of the trade. Being ambitious of raising himself above his condition of a workman, he studied very hard during his apprenticeship, rising at four o'clock in the morning to study mathematics, applied mechanics, hydraulics, and general physics. In this way, by the time his servitude was over, he had qualified himself for a superior walk in life to that for which he seemed destined. He obtained an appointment under his uncle, Mr. George Leather, as out-door superintendent to the Leeds Water-works Company, which he occupied for some years. Early in 1849 he was made foreman over a portion of the works of the Manchester Corporation Water-works, under Mr. J. F. Bateman, Past President Inst. C.E. For the ensuing nine years (1854–63) he was Resident Engineer, and part of the time Manager of new gas-works for the supply of Hyde, in Cheshire; and in July 1863 was made Engineer and Manager of the Corporation Gas-works, Burnley, which position he held until his death on the 20th of February, 1889. Here he had the designing and carrying out of all the extensions and improvements during twenty-six years, the make having increased meanwhile from 51,000,000 cubic feet per annum to upwards of 300,000,000. During this time he erected one large retort-house, two purifying-houses, four gasholder tanks, river-retaining walls, and six gas-holders, three of which are treble lifts.

Mr. Leather was elected an Associate Member of the Institution on the 5th of December, 1882.

STAFF-COMMANDER WILLIAM WALTER KIDDLE, R.N., was born on the 30th of November, 1823. His professional career, having been exclusively a naval one, is best told in the accompanying extract from the Navy List.

"Served as Senior Navigating Officer seventeen years on foreign stations and three and a quarter on channel service or fleet, including three sea-going flagships, Mediterranean, North America, and West Indies and Channel; saw much boat and river service on the west coast of Africa in suppressing the slave trade; present at the capture of seven vessels; received the thanks of the President of the United States for rescuing with the boats of 'Firefly' and 'Dolphin' a brig from the natives of the Congo; served in two Baltic Flying Squadrons, named for boat services, on one occasion with the French, and reported by letter at the close of the war for service before the enemy; in 'Tartar' took three Venezuelan schooners of war from under the guns of Puerta Cabello, and held them till the English flag had been saluted; subsequently commanded for eight years the mail steamers of White Star, West Indian and Pacific Royal Mail Companies; has the French Gold Medal of Honour, Baltic Medal, Royal and Liverpool Humane Societies Medals, and Medal for Nautical Astronomy; also two testimonials from the Liverpool Humane Society, and one from the Prefect of the Rhone; publicly thanked and logged for gallantry in 'Medusa' and 'Royal Alfred,' and holds a Certificate for the same from Commander of 'Firefly'; received several substantial presentations and letters of thanks from public companies, &c, &c., including one from the French Consul-General at New York. *Vide* Royal Humane Society's Medals, and Liverpool Shipwreck and Humane Society's Medals."

About the year 1877 Captain Kiddle was appointed Principal Officer of the Board of Trade and Chief Emigration Officer, Ireland, with headquarters at Dublin. He continued to hold office till his death, which occurred in London on the 27th of June, 1889.

Captain Kiddle was a Younger Brother of Trinity House, and was elected an Associate of the Institution on the 5th of February, 1878. Besides possessing professional abilities of a high order, he was a most accomplished man, being an artist in water-colours of considerable repute, a well-known contributor to periodical literature, and a good linguist, reading and speaking five languages.

JOHN PHANUEL ROE was born in Ireland, where his father, Mr. Peter Roe, was a merchant and landowner; but late in life, meeting with reverses, he came to England, when the subject of this notice was a lad of fifteen. Mr. J. P. Roe was educated at Salisbury, his studies being directed with a view to his entering the medical profession, but a strong liking for mechanics led him to abandon that idea. In the result, he was articled to Mr. William Llewellyn, public-works and mining engineer, of Pontypool. On the expiration of his pupilage, in 1835, he entered the Dowlais Ironworks as a draughtsman and assistant engineer, being afterwards advanced to the charge of some of the mines. He next engaged with the Rhymney Iron Company as assistant engineer, under Mr. Richards, and on the death of that gentleman, shortly after the works were commenced, succeeded to him as Chief Engineer, completing the undertaking, and building five blast-furnaces, with blowing-engines; also designing and erecting pumping- and mining-machinery of various kinds, together with extensive rolling-mill machinery. He organized a locomotive line between Rhymney and the shipping berths at Newport, besides largely introducing locomotive haulage in other directions, notably upon the Company's limestone road, previously worked by horses, where, after bettering some of the curves and steeper portions, suitable locomotives were successfully worked on grades of 1 in 28; shoe or skid brakes, acting on the rails, were used. Mr. Roe, about the year 1845, designed and constructed, to the best of his own belief, the first eight-wheeled double-bogie locomotive to haul heavy traffic. The engines had an intermediate shaft, which was connected to the bogies, so as to allow of freedom of movement.

From Rhymney Mr. Roe went to the Nantyglo and Beaufort Ironworks, as Chief Engineer, under the late Mr. Crawshay Bailey; and from there to the late Mr. William Crawshay, as Chief Engineer to his works and mines at Cyfarthfa, Treforest, and Newbridge (South Wales). Here again he had to do with the designing, erection, and maintenance of blast-furnace, mill, mining, and pumping plant. While at Cyfarthfa he designed and applied a travelling steam-racking engine for discharging an extensive installation of coke ovens, and about the year 1855 introduced trip-expansion gear to one of the blast-engines. This gear was probably the first of a general type that has since been developed and largely used in various forms. During Mr. Roe's Cyfarthfa engagement, he was consulted by the Llynvi Iron Company, for whom he afterwards became General Manager and Engineer, designing and erecting at the works mining, furnace, mill, and other machinery, and generally remodelling the plant. Here, also, he devised and put to work with great success probably the first direct-acting mill engine, driving the roll train without the intervention of spur-wheels. This mill, when rolling small rods, worked at 400 revolutions per minute, and, in spite of the comparatively limited choice of material at the designer's command in those days for such speeds, the mill was in 1887 still working satisfactorily. When at Llynvi, he built also branch lines and several bridges to connect the works with the Llynvi Valley Railway. In 1867 Mr. Roe went into business at Cardiff as a consulting and general engineer and iron-founder, where he designed and built a quantity of mining, hydraulic, and mill plant. But his commercial instinct was not on a par with his engineering abilities, and he lost a large sum of money in this venture, which he subsequently abandoned, and went to the West Cumberland Works at Workington. There he put up extensive steel-making plant, and remodelled portions of the older parts of the ironworks.

From Cumberland Mr. Roe went to the Consett Company, County Durham, as Chief Engineer, where he remained for the rest of his life, engaged in the designing and laying out of the most modern and powerful iron and steel manufacturing plant of various kinds. He rearranged parts of the works, railways, and other means of communication, and designed and constructed one of the most powerful and, of its kind, complete steel plants, embracing several new departures in the direction of economy of working. He, at Consett, also designed and put up very extensive brickmaking works, possessing several new features, which have produced very satisfactory results as to economy and quality of work done. Among these is the utilization of otherwise waste heat from batteries of coke-ovens built in conjunction with the brickmaking-works, whereby the use of outside fuel for drying and burning the bricks is reduced to a nominal quantity.

While with the Consett firm Mr. Roe advised the Orconera Iron Ore Company, of Bilbao, as to its appliances, and designed the large shipping-staithes at Luchana, with telescopic shoots and other devices for rapidly loading large craft under the special local conditions and requirements. He also acted as consulting engineer in reference to the heavy curved gravity incline, and various transport, mining, and other plant, designed chiefly in Spain, by his son, Mr. Pearce Roe, who was the Company's Resident Engineer. He was still fully engaged in professional matters when he died, on the 8th of September, 1888, in his seventy-fourth year.

From the above record it will be seen that Mr. Roe was an active worker for nearly sixty years. He was a man of great breadth of reading and general knowledge, and an ardent lover of Nature, whose lessons, as applied to engineering, he was never tired of learning. He was very inventive, and schemed a great variety of appliances of all kinds in connection with the manufacture of iron and steel; but, owing to a naturally retiring nature, he never published his doings. He was elected an Associate of the Institution on the 1st of February, 1842, and though long since qualified for full membership, never cared to fulfil the formalities necessary for his transfer to the higher grade.

COLONEL HAMILTON TOVEY, R.E., Commanding Royal Engineer of the Home District, was born at Stoke, Devonport, on the 16th of July, 1841, being the youngest son of Captain Alexander Tovey, of H.M. 24th Regiment, and of Elmsleigh, near Paignton, South Devon.

After being educated at the Ordnance School, Carshalton, and the Royal Military Academy, Woolwich, he was commissioned a Lieutenant of Royal Engineers on the 22nd of June, 1858, and passed through the usual year's course of instruction at the Royal Engineers Establishment, Chatham.

He was then quartered at Portsmouth for more than two years, and had the honour, in 1860, of turning the first sod of the great fortifications of Portsdown Hill, where his smart little camp of sappers was always an object of much interest to the neighbourhood.

In December 1861, on the outbreak of the "Trent" affair, Lieutenant Tovey was suddenly ordered to Canada in Captain (now Colonel) E. O. Hewett's 18th Company Royal Engineers, who, after an effort to land with their comrades the Scots Guards, at Rivière du Loup—defeated on account of the rapidly accumulating ice—had to steam away to Sydney, Cape Breton, thence to Halifax, and finally to St. John, New Brunswick, where they disembarked after a voyage of some thirty-five days. They crossed New Brunswick in sleighs to Rivière du Loup, the Canadian Railway terminus, and thence to London, Ontario, a land journey of over 1,100 miles; but to their chagrin they never saw the active service they had all anticipated. At London Lieutenant Tovey was employed chiefly in surveying for military positions and in providing temporary barrack-accommodation for an unusually large force, numbering ten times the normal garrison. In June, 1863, he left with his company for Pictou, Nova Scotia, and thence by road-march to Halifax. At the end of his tour of foreign service he was quartered at Bermuda for five months.

On returning home in 1867 he served five years at Plymouth (where he built Picklecombe Fort), Chatham, and Aldershot, between July, 1867, and May, 1872. During this period he was employed, in 1871, upon the buildings of the Annual International Exhibitions at South Kensington.

After leaving Aldershot, in May, 1872, Captain H. Tovey, R.E., renewed his acquaintance with the fortress of Portsmouth for some four years, broken only by the episode of his being ordered abroad on active service in March 1874, with the result (so painful to a soldier) that he had merely to come home again after a two months' absence, for, when he arrived at the Gold Coast, the Ashantee War was over.

Taking part in the autumn manœuvres at Dartmoor, in 1873, as Commanding Royal Engineer in the 1st Division, he headed the list of officers specially thanked by Major-General Sir Charles Staveley, K.C.B., commanding the Army Corps, "for the assistance rendered to me . . . in laying out the encampment of brigades, in the absence of divisional and brigade staffs, when the troops were first assembling."

From Portsmouth he was moved, in October, 1876, for five years to the Army Manufacturing District, his particular duty being the charge of the engineer works of the Royal Gunpowder Factory at Waltham Abbey, and the Royal Small-Arms Factory at Enfield.

Then, after spending more than a year at Chatham and Aldershot, Major Tovey was appointed, in December, 1882, "Instructor in Strategy, Military History, and Law" at the School of Military Engineering at Chatham.

In that appointment, which he held for nearly three years, he wrote two valuable books, "The Elements of Strategy," and "Martial Law and the Custom of War, 1886." The former gained from the Commander-in-Chief the honour of an official "expression of His Royal Highness's satisfaction with the careful and diligent research which he has taken in the compilation of his work"; and the latter has been stated by some experts to be the best work on Military Law published in this country since the passing of the Army Act of 1881.

Lieutenant-Colonel Tovey served again in the Southern District from September, 1885, as Commanding Royal Engineer of the Gosport Sub-District, and he was, in that capacity, reported to headquarters by the general of the district for his valuable services as Secretary to the Committee on the Defences of Portsmouth and Weymouth.

On the 30th of June, 1888, he came to London as Commanding

Royal Engineer of the Home District, and in that command he died, at his house, 39, Nevern Square, South Kensington, on the 5th of August, 1889, after more than thirty-one years' service in the Army. He was elected an Associate of the Institution on the 5th of February, 1878.

Colonel Tovey never had the chance to achieve any great distinction, nor the good luck to see a shot fired in anger, but he was a sterling engineer, never sparing himself in carrying out thoroughly any work confided to him. He had the shy, reserved manners so often noticeable in military men, and by some termed "stoicism," but he was truly a warm-hearted benevolent, beneficent man and an earnest soldier.

Perhaps the most notable part of his life was its close. He had been ailing for some months, and merely attributed his state of health to the change from his ordinary open-air life to a sedentary life in London; but he took good medical advice. At last, however, it was thought desirable to supplement that advice by the opinion of a specially-eminent physician, who diagnosed the subtle malady to be one of fatal character, which would terminate life in about a week, and he broke the news to his patient, who received it with characteristic coolness.

Colonel Tovey busied himself during his few remaining days on earth—to the astonished admiration of his doctors (men well accustomed to see death)—in calmly settling details of business, official and private, so as to save trouble or inconvenience to others. He arranged, for example, as to the disposal of his accoutrements, the sale of his charger at Tattersall's, and so on. It seemed that he had truly thought out his family motto, "*In Deo confido.*"

He acted as if he were merely preparing to go on parade. He wrote to his major (G. R. Savage, R.E.) a letter, forwarding his office keys, and giving minute instructions on business matters, and bidding farewell to his officers and subordinates, saying, "My days are numbered, and I am daily getting weaker. Bid good-bye to . . ." and his pencil-written letter ended with an apology, in curiously punctilious courtesy: "Excuse pencil, for I am in bed. Good-bye."

In the Army they often have to say "Good-bye," but it may be doubted if a soldier's last "Good-bye" was ever more bravely expressed.

⁂ The following deaths have occurred, or been made known, since the 2nd of August last, in addition to some of those included in the foregoing notices :—

Members.

Fulton, Arthur Robert William; *born* 3 October, 1853; *died* 26 July, 1889.

Hall, Richard Thomas; *born* 31 May, 1823; *died* July, 1889.

Lee-Smith, Hamilton; *born* 25 December, 1829; *died* 3 September, 1889.

Vawser, Robert; *born* 13 September, 1841; *died* 15 September, 1889.

Willcox, William; *born* 18 January, 1830; *died* 14 August, 1889.

Associate Members.

George, John Rees; *died* 26 June, 1889, *aged* 49.

Rhind, James; *born* 31 May, 1848; *died* 11 September, 1888.

Wood, Alfred Hope; *born* 29 March, 1826; *died* 15 September, 1889.

Wood, Edward Walter Nealor, *born* 11 January, 1856; *died* 30 August, 1889.

Associate.

Hancox, Joseph; *died* 24 May, 1889, *aged* 62.

Information respecting the life and works, the career and leading characteristics, of any of the above, is solicited, to aid in the preparation of future Obituary Notices.—Sec. Inst. C.E., 30 *September*, 1889.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Note on Tensile-Tests of Metals. By PIERRE ARNOULD.

(Le Génie Civil, 1889, p. 362.)

The Author, after discussing the merits of tensile, compressive, bending, and shearing experiments, points out the great advantages of the first method of testing.

He urges the importance of having the elastic as well as the final elongation measured, and considers that elastic stress-strain diagrams are highly desirable. Various instruments are described for automatically recording both elastic and complete diagrams. For merely determining the elastic limit, the Author prefers the simple method of marking the test-bar after each application of load with a pair of dividers or a trammel.

In the second part of his communication he describes in detail, with eight diagrams, a novel method of testing short lengths of wire rope. The total length of the specimen experimented upon was about 1,100 millimetres (43·3 inches), and the diameter 23 millimetres (0·91 inch). After binding the cable in two places, 900 millimetres (35·43 inches) apart, with a few rounds of iron wire, he frayed out the ends of the rope, and turned each wire back to form a loop, and after cleaning the "broom" thus formed with turpentine and acid, he cast on two conical ends to fit the jaws of his testing-machine, the alloy being an equal mixture of zinc and lead; these ends enabled him to grip the cable and give it the desired tension. The elongations were measured with a special apparatus described and illustrated, the stress-strain diagram being plotted afterwards from these observations.

The diagram exhibits several interesting features, which are discussed under four heads:—

(1) A portion of the curve—concave to the stress-axis—corresponding to the period during which the cable straightens under the tension up to about a load of 1 tonne (0·98 ton = 2,195 lbs.).

(2) Still concave to the stress-axis, while the wires are being drawn close together and squeezing out the tar, up to about a load of 10,000 kilograms (22,046 lbs.).

(3) Straight line, corresponding to the elastic period, up to about 20,000 kilograms (44,092 lbs.).

(4) Convex to stress-axis, corresponding to the permanent stretching and gradual destruction of the cable, continuing until fracture occurs at about 31,300 kilograms (69,000 lbs.).

J. G.

The Influence of Temperature on the Mechanical Properties of Metals. By ANDRÉ LE CHATELIER.

(Comptes rendus de l'Académie des Sciences, Paris, vol. cix. 1889, p. 24.)

The properties of metals at temperatures to which they are exposed in industrial applications, specially in boilers, are little known. The Author undertook to examine them in the case of iron and steel, and extended the inquiry to some other metals and alloys.

The test-specimens were annealed wires $\frac{1}{4}$ inch in diameter. They were placed horizontally, and heated over a length of 6 inches in a thick brass tube. The thick tube was intended to distribute the temperature uniformly. The tension was exerted by a wire passing over a pulley, and supporting a cistern into which water could be discharged. The wire carried an index for measuring the elongations.

The tension per unit of area necessary to produce fracture in a short time (thirty minutes as a maximum) decreases as the temperature increases, and the elongations produced by a given load, short of the breaking-weight, increase with the temperature.

The breaking-weights are given in the following Table; in tons per square inch, the temperatures being Centigrade:—

	15°	100°	150°	200°	250°	300°	350°	400°	460°
Copper . .	16·0	14·5	12·0	10·7	8·8	8·1	6·0	4·4	2·3
Aluminium.	11·7	9·5	8·1	6·3	4·8	3·6	2·4	1·5	1·0
Nickel . .	35·0	35·0	35·0	34·9	34·2	32·3	27·9	23·4	19·3
Silver . .	10·9	10·1	8·6	7·2	5·6	4·5	3·8	3·3	3·0
Aluminium bronze .	33·8	33·3	32·3	31·2	29·8	28·1	23·4	14·7	6·3
Copper, iron, nickel .	26·9	26·8	26·3	25·8	24·9	23·4	17·7	11·6	5·0
Zinc. . .	7·9	1·5	0·6	0·4	..	0·4	..	..	..

The Author distinguishes a kind of elongation which, while not proportional to the load, is not confined to a short length of the bar. He terms this elongation by annealing. This elongation occurs in all metals above a certain temperature; above 15° for copper and silver, above 70° for zinc, above 280° for aluminium, and above 350° for aluminium bronze, nickel, and its alloys. The minimum load necessary to produce elongation by annealing with a sensible velocity (rupture in thirty minutes) is very great at these limits of temperature. That minimum load decreases rapidly with increase of temperature. The temperature of complete annealing is attained at 150° for zinc, 500° for aluminium, and above 500° for other metals. The results for iron and steel will be the subject of another communication.

W. C. U.

Permeability of Cements and Cement-Mortars under Pressure.

By L. M. Haupt.

(Journal of the Franklin Institute, September 1889, p. 199.)

The experiments here noticed were made by Messrs. G. W. Hyde and W. J. Smith, University of Pennsylvania, by means of four cylinders 3 inches in diameter, in which the specimens to be tested were placed, joined to a 3-inch main pipe, through which the pressure was transmitted to the specimens from a hand-pump at one end. The specimens were 3 inches thick. The pressure was maintained at three degrees—75 lbs., 100 lbs., and 200 lbs. per square inch respectively—and for three hours in each experiment. Six series of experiments were made: with neat cements, after setting seven days and after setting twenty-eight days; cement-mortars, composed of equal parts of cement and sand, after seven days and after twenty-eight days; and cement-mortars mixed in the proportions of 1 to 2, after seven days and after twenty-eight days. The samples were allowed to drain for one day. Each sample of cement was sifted through a sieve of 40 meshes to the lineal inch. The sand was passed through a sieve of 25 meshes to the inch. Eight brands of cement were tested.

The results are given in several large tables, with diagram curves of discharge of water, from which the following Table has been abstracted:—

Discharge of Water through Samples under Pressure.

Sample.	Number of Samples.	Pressure per Square Inch.		
		75 lbs.	100 lbs.	200 lbs.
		Water passed per Square Inch in 24 Hours		
		Quarts	Quarts.	Quarts.
Neat cement, 7 days.	5	0·033 to 0·091	0·006 to 0·092	0·040 to 0·267
„ 28 „ .	1	0·034	0·052	0·138
Mortar, 7 days Mixture, 1 to 1	3	1·503 to 12·397	2·336 to 17·096	6·323 to 36·207
Mortar, 7 days Mixture, 1 to 2	5	2·107 „ 42·546	3·310 „ 52·554	10·508 „ 101·268
Mortar, 28 days Mixture, 1 to 1	3	0·328 „ 1·704	0·551 „ 2·482	1·413 „ 4·471
Mortar, 28 days Mixture, 1 to 2	5	1·941 „ 34·006	3·012 „ 13·815	6·616 „ 31·482

D. K. C.

The Manufacture and Properties of the Cements of the Isère.

By A. Gobin.

(Annales des Ponts et Chaussées, vol. xvii. 1889, p. 755.)

In the Department of the Isère in France are a number of deposits of argillaceous limestones, suitable for the manufacture of hydraulic cements. This Paper describes the most important deposits in detail, together with the processes of manufacture, and the resulting products in each case. One of the oldest known deposits is that of Porte-de-France, near Grenoble, on the right bank of the Isère. This was discovered in 1842, and has since been worked by various firms. There are three layers, belonging to the lower cretaceous series, their position being nearly vertical. One of them is 14 feet 9 inches thick, and each of the other two about 5 feet. The stone is extracted through underground workings, by means of a wire rope-way. The cables are 600 metres (656 yards) long, and the difference in level between the two extremities is 310 metres (339 yards). The tension is regulated by means of a movable truck loaded with 2,000 kilograms (1 ton 19 cwt.), and attached to the lower end of the cable. The speed is controlled by a Prony brake.

The limestone is burnt in continuous kilns by pulverized anthracite, which is wetted previous to use. The stone is reduced to pieces of uniform size to ensure regularity in burning. The consumption of fuel is 180 kilograms (397 lbs.) per ton of stone, and the operation lasts ten days. On leaving the kiln, about two-thirds of the charge consists of yellowish fragments, retaining their original shape. This forms the quick-setting cement. The remaining third is composed of black, heavy clinker, which is picked out by hand, and used for making the slow-setting cement.

Both kinds of cement are ground in ordinary horizontal mills, 1·70 metre (5 feet 7 inches) in diameter, and making 70 revolutions a minute. The quick-setting cement is sifted through a No. 50 sieve, and passed into stores, where it is kept two or three months. This cement has a density, when not shaken down, of 1·15, and sets in from five to ten minutes, according to the prevailing temperature. The slow-setting cement, called natural Portland, is sifted through a No. 60 sieve, and then stored for three or four months at least before being issued. It sets in fifteen to twenty minutes. Although the bulk of this natural Portland is a by-product from the manufacture of the quick-setting cement, yet the greater part of the charge of the kilns can be obtained as clinker by augmenting the proportion of fuel to 250 kilograms (551 lbs.) per ton. In this case the burning is intermittent, and any yellow fragments must be picked out by hand. The burning takes twenty-one days.

This slow-setting cement has a density of 1·4, when not shaken down, and sets in from fifteen to twenty minutes.

An artificial Portland cement is also made at Porte-de-France. The materials used are the waste from the manufacture of hydraulic lime, and the clinker which gives the natural Portland cement. Four parts of the waste are ground with six parts of clinker, and the resulting powder is stored for at least four months before use. Cement made in this way has a density of 1·35, and sets in three hours. At these works a new grinding apparatus has been introduced to take the place of the horizontal mills. It consists of a vertical cylinder 1 metre (3·28 feet) in diameter, within which a shaft, provided with six arms, revolves, carrying with it six loose steel balls, each 0·20 metre (7·87 inches) in diameter, and weighing 35 kilograms (77 lbs.) each. The upper part of the cylinder is furnished with a wire sieve, through which the ground product passes. The speed is 180 to 200 revolutions a minute. The power required is said to be less than with the ordinary horizontal mills.

In some of the factories a conical sieve is in use, which contains only 3 square metres (3·588 square yards) of wire netting. Eight of these sieves are required for three pairs of stones.

During the process of manufacture numerous samples are taken and tested. Should any of these samples show signs of weakness when immersed in water for eight or ten days, the bulk of the cement is retained in store until renewed tests show it to be reliable.

Analyses of the materials and finished cements are given, from which it appears that the two natural cements contain about 56 per cent. of lime, while the artificial Portland contains 57 per cent. The amount of magnesia in the Portland cement is 2·4 per cent., and of sulphuric acid 1·8 per cent.

At Voreppe, near Grenoble, four kinds of cement are made. The materials are of the same geological formation as at Porte-de-France, but the layers are inclined at an angle of 45°. They are worked by means of inclined underground galleries.

The kilns are 10 metres (32·8 feet) in height, and the draught is increased by means of a main chimney, connected by flues with the kilns. The draught is further regulated by iron covers to the kilns, which can be raised or lowered as required. The fuel used is anthracite, with a little steam coal. For the quick-setting cements the working of the kilns is continuous, and for the Portland cement intermittent. The general process of manufacture is similar to that adopted at Porte-de-France, and the finished cement is stored at least six months before being issued. The sieves used are flat, inclined at an angle of 45°, and are kept in a state of vibration.

In chemical composition these cements differ but little from those of Porte-de-France. The Portland cements are slightly richer in lime, and consequently set more slowly. The crushing strength per square centimetre of the slow-setting Portland cement is 129 kilograms per square centimetre (1,834 lbs. per square inch) in ten days, and 458 kilograms (6,514 lbs. per square inch) in one year.

At Grenoble and Tenay six kinds of cement are manufactured, the time of setting of which varies from three minutes to three hours. Here again the materials belong to the same geological formation as those of Porte-de-France. The bulk of the cement is made from a layer of limestone 4·50 metres (14·76 feet) thick, containing about 24 per cent. of clay. The outer portions of this layer contain a larger proportion of carbonate of lime, and can be distinguished after burning. They are picked out by hand, slaked by sprinkling with water, and afterwards ground and sifted.

The artificial Portland cement is made of a mixture of three materials, viz., the waste from the manufacture of hydraulic lime, clinker produced during the burning of the quick-setting cement, and clinker made of an artificial mixture of marl and limestone. The latter mixture is burnt for a fortnight in intermittent kilns. The finished Portland cement contains 50 per cent. of lime and 3 per cent. of magnesia. The tensile-strength of the neat cement in twenty-eight days is 48·6 kilograms per square centimetre (691 lbs. per square inch).

A limestone belonging to the Lias formation yields the raw material for two varieties of cement manufactured at Valbonnais. The layer used is 4 metres (13 feet) in thickness, and is worked through three galleries, the lower of which forms an inclined plane. The stone is burnt in kilns working continuously, and the product is afterwards picked by hand. The harder clinkers yield a slow-setting cement, which is stored two or three months before use. The percentage of lime in this Portland cement is 55·7, and of magnesia 0·5. Sulphuric acid is present to the extent of 2 per cent. At La Mure, a church, 52 metres (170·5 feet) in length, is being built almost entirely of concrete blocks made with this cement.

Vicat's slow-setting Portland cement has been made since 1857 at Genevray, near Grenoble. The original factory was pulled down last year to make room for new stores. The raw materials are a rich lime, made by burning a pure limestone, and a highly argillaceous limestone, containing 40 per cent. of clay. These two are mixed in such proportions that 23 parts of clay would unite with 77 parts of carbonate of lime. The argillaceous limestone is heated at a temperature which is too low to expel the carbonic acid, and is then ground and sifted through a No. 55 sieve. An automatic apparatus takes a sample from each sack of ground material. These samples are analyzed, and serve to regulate the proportions of the mixture. The rich limestone is first burnt, then slaked by placing in perforated iron vessels, which are immersed for an instant in water. The contents are then discharged upon a grating, where the lime slakes and falls through, leaving the slags and imperfectly-burned pieces upon the grating. In six or seven days the slaked lime is sifted through a No. 60 sieve and removed to stores, where samples are taken for analysis. The pulverized raw materials are mixed by weight in proportions dependent upon the chemical composition. The mixed powder is then moistened, moulded into bricks, and dried in the open air. The kilns, which are forty-two in number, have a total height of 10·50 metres (34 feet), and a diameter of 2·50 metres (9·2 feet) or 3 metres (9·84 feet). Before charging into the kiln the bricks are broken into small fragments, which are arranged in layers alternately with anthracite. The proportion of fuel used is one-sixth of the weight of the briquettes, and varies in different parts of the kiln. The clinker from the kilns is first broken in a stone-crusher, and ground in mills of the usual type. The cement is then sifted through a No. 60 sieve. Samples of the finished product are taken, and the briquettes are not only tested for tensile-strength but are frequently analyzed as a check upon the proportions of the raw materials. The tensile-strength of a mixture of 1 part by weight of cement with 3 parts by weight of standard sand is also ascertained. The sand is prepared by sifting siliceous sand through a sieve of 64 meshes per square centimetre (413 meshes per square inch). That which passes through is again sifted through a sieve of 144 meshes per square centimetre (929 meshes per square inch), and the sand remaining upon the latter is used for the experiments. Each series of tests is made with forty-four briquettes of a breaking section of 16 square centimetres (2·48 square inches). These are broken at periods varying from five days to a year, the same system having been carried out since the establishment of the factory. The time of setting of this cement varies from eight to twenty-four hours, according to the temperature. The percentage of lime is 61·25, of magnesia 1·90, and of sulphuric acid 1·70. The tensile-strength of the neat cement in twenty-eight days is 33·83 kilograms per square centimetre (481·16 lbs. per square inch), and the crushing-strength in the same time 372·3 kilograms per square centimetre (5,295·16 lbs. per square inch). Mixed with 3 parts of sand, the figures are 19·67 kilograms per square centimetre (365·5 lbs. per square inch) and 177·3 kilograms per square centimetre (2,521·7 lbs. per square inch) respectively.

At Uiriage a natural cement is made by the same firm from a limestone of the Lias formation. This stone is traversed by irregular white veins of carbonate of lime, which are carefully picked out before burning. The kilns are 6 metres (19·68 feet) high and 3 metres (9·84 feet) in diameter, and are worked continuously. The manufacture of this cement is similar to that of the other natural cements of this district. The finished product contains 47·30 per cent. of lime, and 1·95 of magnesia, with 2·20 per cent. of sulphuric acid.

Near La Grande Chartreuse two kinds of cement are manufactured from a layer 3 metres (9·84 feet) thick, belonging to the Neocomian formation. The strata are inclined at an angle of 43°, and the stone is extracted through twenty-two galleries, each 3·50 metres (11·48 feet) in height. The difference in the quality of the two cements produced here is chiefly due to the mode of burning. The heavy, or slow-burning, cement is burned for three weeks, during which process about 10 per cent. of dust is produced, which is rejected. The proportion of lime in these cements is 54·5, of magnesia 3·5, and of sulphuric acid 4 per cent.

The quick-setting Grenoble cements are largely used for gas- and water-pipes, sewers, and other hydraulic work which must be executed rapidly. The general composition of the concrete is 1 part, by volume, of gravel to 1 of cement.

Referring to the discrepancies so frequently noticed in the weights of the same cements when taken by different observers, the Author proposes to weigh a given volume of cement after it has been subjected to a series of two hundred and fifty or three hundred shocks in a litre vessel of metal 0·172 metre (0·564 foot) in height, and 0·086 metre (0·282 foot) in diameter. The cement should fill the measure loosely at the commencement of the experiment, and the distance to which it sinks when shaken down will be an indication of the relation between the weight when weighed in the loose state and when packed. It was found that the density of a cement did not perceptibly increase when the number of shocks given to the vessel was greater than three hundred. The increase in density by this method was about 30 per cent., as compared with the powder measured loose. The microscopic examination of a cement is recommended as a means of detecting impurities, and of controlling the fineness of grinding.

In storing the ground cement, it has been noticed that there is an increase of temperature of about 8° Centigrade (14°·4 Fahrenheit), especially during moist weather. Storing the cements for two or three months before using is general, and appears to be necessary. With the Portland cements especially the time of setting is considerably increased by storing. In the cements examined, the percentage of sulphuric acid varied from 1·65 to 3·70. Experience has shown that even 4 per cent. of this substance has no injurious effect when the cement is used in fresh water. When exposed to salt water, so high a proportion of sulphuric acid would prove injurious, owing to the formation of sulphate of magnesia.

W. F. R.

The Manufacture of Slag-Cement. By J. GROSCLAUDE.

(Annales Industrielles, July 21, 1889, p. 89.)

The manufacture of cement from slag has, in the last few years, become rapidly extended, and works are now in operation in France at Saulnes and Marnaval, in England at Middlesbrough, in Switzerland at Choindez, at many places in Germany, and at Bilbao in Spain. The quality of the cement varies considerably in accordance with the composition of the raw products employed, and the care exercised in the manufacture, but the material when well made will bear comparison with the best Portland cement. The slag employed should be basic, and must be previously granulated on the system of Mr. C. Wood, as otherwise it is devoid of hydraulic properties. According to Professor Tetmajer, of Zurich, the lime, silica, and alumina in the slag, should bear to one another approximately the following proportions: as 46, 30, 16. Fat or pure limes are generally selected to add to the slag, but the Author counsels the adoption of poor or clayey limes, in cases where the cement is to be used above ground. Where much calcium sulphide is present, as in the Bilbao slags, the cement takes a greenish tinge, but this does not impair its quality. A sample tested by Professor Tetmajer, composed of 100 parts of Bilbao slag and 15 parts of lime, was found on analysis to give the following percentage results: silica 30·56, alumina 13·31, oxide of iron 0·25, oxide of manganese 1·74, oxide of lime 45·01, magnesia 2·96, sulphate of lime 1·41, and sulphide of calcium 4·63. Briquettes of the neat cement were tested as follows:—

	Seven days.	Twenty-eight days.
Strength in compression per square centimetre—	Kilograms.	Kilograms.
In water	96·9	120·9
In air	..	144·0
Tensile-strength per square centimetre—		
In water	19·3	28·7
In air	..	19·5

The mode of preparing the slaked lime and the apparatus used for the purpose is explained by reference to diagrams. Drawings are given of various descriptions of drying machines which have been employed for desiccating the granulated slag; the rotary drier, invented by Mr. Ruelle, is preferred by the Author, and a novel form of apparatus, patented by Mr. Raty, of Saulnes, is described and fully illustrated. For the intimate admixture of the slag and slaked lime, and for grinding the same to a fine powder, the apparatus of Mr. Luther, of Brunswick, is employed. This consists of an iron cylinder with a corrugated lining, partly filled with small metal balls, by means of which the materials are both ground and mixed in one operation, which lasts about three quarters of an hour for each charge. The cement thus prepared leaves a residue of from 5 to 6 per cent. on a sieve of 2,500 meshes per square centimetre. A sample of slag cement made at the Donjeux factory was officially tested at the École des Ponts et Chaussées in September 1888, with the following percentage results: combined silica 23·85, alumina 13·95, peroxide of iron 1·10, lime 51·40, magnesia 1·95, sulphuric acid 0·45, sand 0·25, loss on ignition 7·05. It left on a sieve of 5,000 meshes per square centimetre a residue of 23 per cent.; gauged with 28 per cent. of water, the initial set took place in one and a quarter hour, and the set was complete at the end of three hours. On the mean of six tests the neat cement showed the following tensile-strength per square centimetre: in seven days 21·87 kilograms, in twenty-eight days 26·88, and in eighty-four days 31·15 kilograms (equivalent per square inch to 311·06 lbs., 382·32 lbs., and 443·05 lbs. respectively). Briquettes of 3 parts sand to 1 cement broke in seven days at 14·93 kilograms, in twenty-eight days at 26·03, and in eighty-four days at 29·23 kilograms (equivalent per square inch to 212·35 lbs., 370·23 lbs., and 415·74 lbs. respectively). Tables too long for abstract indicate the composition of twenty-three different samples of slags from various foreign furnaces, together with tests of the cements made from the same.

An estimate is given of the cost of the plant for a works capable of producing 6,000 tons of cement per annum, and of the necessary materials for the same, also of the expense of manufacturing the cement and the profits on the manufacture. The estimate is accompanied by plans and sections of the factory.

G. R. R.

Utilization of Waste Products.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereins, 1889, p. 215.)

After pointing out various new substances that have resulted from the successful utilization of waste products, such as perfumes and saccharine from coal-tar refuse, the Author proceeds to show that a good and useful building material may be produced by roasting at a temperature of 302° Fahrenheit, the rubbish obtained from old buildings; that by such process so much water is driven out of the material as to reduce the volume from 20 to 40 per cent., and hence the employment of such a perfectly dry material in a building will prevent the settlements so often observed, resulting from the drying of the material within the walls of the building itself. A further advantage is a sanitary one, for while the original waste product may contain within itself the germs of disease, these are destroyed by the intense heat to which they are subjected in roasting, and the material is therefore completely disinfected.

Another useful building material is manufactured from blast-furnace refuse in the form of bricks and paving slabs, and this has established a new industry in the smelting houses on the Schwechat near Vienna, where the furnace slag is broken up and mixed with hydraulic lime and then moulded under steam-pressure into bricks. The value of the product consists in the formation of silicate of lime from the combination of the silica in the slag with the lime, resulting in a hard material which increases in hardness on exposure. The brick in this condition is of a uniformly greyish white colour of rather coarse grain and very sharp edges, and possesses in a high degree the two valuable properties of permeability and porosity, and thus constitutes an essentially healthy building material. The durability of the material too has been tested by a fifteen years' exposure in some cases, and no signs of wear or weathering have been noticed; in short the results of its employment have been so favourable that it has been recommended by the Board of Works for general purposes, and to be used with a mortar made from slag, sand and hydraulic lime.

Paving slabs are now made according to a patent process by mixing furnace slag with Portland cement and other constituents, which produce rapid hardening and great strength, and such pavements are now laid down for special purposes in London, Paris, and Vienna.

W. H. E.

The Renewal and Reconstruction of Iron Bridges in Austria.

By Ludwig Huss.

(Zeitschrift des osterreichischen Ingenieur- und Architekten-Vereins, 1889, p. 59.)

About two years ago an iron bridge of ordinary type, on one of the Austrian railways, broke down suddenly under a train, although it had been constructed not ten years previously. The Board of Safety immediately issued a general order for the examination, revision of calculations and renewed testing of all iron bridges; and, with the assistance of the most experienced engineers in the Empire, drew up a revised order for the construction of all future bridges. The work necessitated under this general order developed an entirely new phase of industry, and much information and material relative to the strengthening and renewal of iron structures was also accumulated.

The iron bridges on Austrian railways constructed before the date of the above order may be referred to two periods; the first from about 1857—when the first iron bridges were constructed—to August 30th, 1870, when the first general order was issued relative to the conditions to be observed in iron structures; and the second period from the latter date to September 15th, 1887, when the new order was issued.

Many of the earliest types of bridges, such as those constructed on the systems of Langer and Schifkorn, and some fish-bellied arrangements of double-headed rail-girders, have already been abolished; and the generality of the bridges of the first period are now altogether too weak for present traffic. This deficiency is most conspicuous in the bridges of 60 to 165 feet span, and notably those of about 100 feet span. Bridges of spans from 6 feet 6 inches to 40 feet, *i.e.*, plate-girders, are more generally suited to the loads.

Apart from the wear and tear of the structures in question, the two most important factors in increasing the strains have been the increase in the weight of locomotives and the increased speed of the trains. In 1848 the average weight of engine and tender was 30 tons, in 1878 it was 40 tons, and is now 45 tons; and on the State railways in 1858, 34 tons; 1868, 37 tons; 1878, 43 tons;

1888, 52 tons; in both cases an increase of about 50 per cent.[1] There has been a similar increase of at least 50 per cent. in the average speed of trains during the same period.

All these iron bridges are supposed to have been originally constructed with a factor of safety not less than 4; but there can be little doubt that in many cases the margin was much less, and that many girders strained originally to nearly 7½ tons per square inch, have of late years had this strain increased to more than 12 tons. That these unexpected strains have been developed must often be set down to faulty calculations, alterations from original design in course of construction, faulty systems of construction and neglect of proper maintenance. Locomotive smoke seriously affects girders under which the trains pass, unless very carefully maintained; while in box-girders open at the ends to the free circulation of air, the original colour has still remained after the lapse of thirty years.

In pursuance of the general order of 1887, the work of examining and strengthening the iron bridges on the Austrian railways was promptly taken in hand. The process of renewal was generally commenced with the smaller span plate-girder bridges, which were quickly completed and involved the smallest cost. The work was generally executed piece by piece without interrupting the traffic, although with double lines it was preferred where possible to close one line of rails and thus complete the work more expeditiously. In some cases, *e.g.*, bridges over streams, an intermediate pier was inserted. With the more important long-span bridges the traffic was in a few cases stopped at each end during the process of reconstruction, passengers being transferred from train to train.

The Author then proceeds to detail typical cases of renewal and reconstruction with which, as Government Inspector, he had to deal. A great number of plate-girder bridges, dating from 1857 and following years, were strengthened by the addition of extra plates in the flanges, and stiffeners and flat plates on the webs, and by the addition of cross-girders and transverse bracing. Previous to the execution of these repairs, the flanges were in certain cases found to be sustaining a strain of 8·4 tons per square inch, rivets 7·3 tons, and the edge of rivet-holes as much as 26·7 tons. There was no transverse bracing.

Some continuous girders were treated in a similar manner, while others were disconnected to form two or three independent girders. This course was adopted so that the flanges could be strengthened in the centre of the spans, whereas otherwise the additional material would have been required over the points of support and have involved lifting the girder from the bed-plates.

Other renewals were carried out according to the system of construction dealt with. With shallow main-girders under the rails, intermediate parallel girders were inserted; with lattice main-girders and plate cross-girders, the latter were stiffened with

---

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvi. p. 386.

T irons; and where cross-girders of lattice-work had been employed plate-webs were substituted. Other girders were trussed longitudinally from pier to pier, lattice-girders with one system of diagonals were doubled, and double systems made quadruple; in some cases the new material being fully 35 per cent. of the original ironwork.

About two hundred and fifty plate-girder bridges and one hundred and fifty lattice-girder bridges were thus reconstructed. With bridges from 10 to 45 feet span the average additional material was 5·3 cwt. per lineal yard; from 45 to 80 feet span 7·1 cwt. per yard; and from 80 to 200 feet 9 cwt. per yard.

The Paper is illustrated by three plates, showing details of the various types of reconstruction, and the methods of inserting the new material; also of the staging adopted for working, as far as possible, without interruption of traffic.

P. W. B.

Viaduct over the Adda at Paderno. By G. Sacheri.

(L'Ingegneria Civile e le Arti Industriali, 1889, p. 81.)

The short line forming a junction between the stations of Ponte San Pietro on the Bergamo and Lecco railway, and Seregno on the Monza and Como line, crosses the Adda near Paderno, at a height of 246 feet above the mean water-level, at a point where the river has eroded for itself a deep bed, with one bank sloping at about 1 to 1, and the other (opposite Paderno) 1 to 2. The preliminary project was long discussed by the Government engineers, who examined several schemes, that ultimately chosen being one submitted by the Società Nazionale delle Officine di Savigliano, and designed by this company's chief engineer, Mr. G. Rothlisberger, the contract being signed early in 1887. The work was to be executed in eighteen months for a sum of £75,000, and an additional £5,200 for approaches and secondary works; but the time of completion was actually deferred on account of long delay in obtaining the steel bed-plates and pivots of the main arch from the foreign contractors with whom the order had been placed.

The chief feature of the structure is a large central arch supporting the main-girders. The bridge is for railway (single line) and roadway also, the former being carried between the main-girders, and the latter on cross-girders with cantilever ends above. The total length over the abutments is 998 feet, or clear of the abutments 872 feet 8 inches; this length is divided into eight spans of 109 feet 1 inch. Two of the piers are based on the masonry foundations on which the arch rests, four are built on the arch itself, and one pier on the slope of the bank. The chord of the arch is 492 feet long, and the rise 123 feet. It is formed of four separate arches, 13 feet 1½ inch deep at the crown, and 26 feet 3 inches at the springing. At the latter point the total strain on the flanges of the four arches is 2,549 tons, or 637·25 tons to each flange, which is therefore comprised of eight horizontal plates 28 inches by $\frac{3}{4}$ inch, two vertical plates of the same dimensions, and two angle-irons 5 inches by 5 inches by $\frac{5}{8}$ inch, giving a net area of 167 square inches, and a consequent working-strain of about 3·8 tons per square inch. The web is composed of a trellis of vertical and inclined bars, the strain in which is taken at 3·2 tons per square inch. The arches are erected in two pairs, the two forming each pair being 3 feet 3½ inches apart, and well tied with transverse-bracing on both flanges. The two pairs are inclined towards each other, being 16 feet 9 inches apart, from centre to centre at the crown, and 53 feet 7½ inches at the springing.

The piers are composed each of eight columns, formed of T-irons bolted together, and with horizontal ties and vertical cross-bracing, but no longitudinal cross-bracing. The longitudinal main-girders, resting on these piers, are 20 feet 6 inches deep, and 16 feet 5 inches from centre to centre, with a clear width of 15 feet 1 inch. The flanges, 18 inches in width, are of T section, and the lattice-bars quadruple diagonal system. These main lattice-girders carry the plate cross-girders, with longitudinal rail-bearers and oak sleepers, and perforated iron floor-plates. The carriage-way, carried on the upper cross-girders, is 16 feet 5 inches wide, with two footways 3 feet 3½ inches wide, or a total width between the parapets of 23 feet. The parapets are 5 feet high, and 272 feet above water-level.

The chief approximate quantities of material in the structure are—

Masonry work (Moltrasio stone) . . .	176,500	cubic feet.
Granite	42,360	,,
Wrought-ironwork—arches	1,320	tons.
,, ,, girders	950	,,
,, ,, piers	245	,,

The weight of the structure affected by wind-pressure is 2,162 tons; and the moment of resistance to wind-force is therefore about four times the moment of overturning, and even with a pressure exceeding that of the most violent hurricane yet experienced in the country, the resistance would still be nearly double the wind-force.

The temporary bridge and centering occupied ten months in construction, and involved much difficult constructive detail; but the works were carried out to the completion of the whole viaduct without any loss of life.

The Paper is accompanied by two plates, showing diagrammatic figures of the strains, and general views of the structure, and comprises also a full statement of the calculations of the strains in all parts of the structure arising from various loads, wind, changes of temperature, &c., which are further illustrated by diagrams in the text.

P. W. B.

The Moldau Viaduct at Cervena. By LUDWIG HUSS.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereins, 1889, p. 254.)

The railway now being constructed from Tabor to Pisek crosses the River Moldau near Cervena, at a height of 213 feet above low-water level, by a viaduct of three spans each 262·4 feet wide in the clear at the top of the pier, and with two small openings at the abutment ends. The line is single, and crosses the bridge in a horizontal straight line.

The three main openings are spanned by iron lattice-girders; the supporting masonry piers are bedded on hard granite rock, and are respectively 190 and 203 feet high above the foundation, with sections 16 feet 8 inches by 26 feet at top and 38 feet by 47½ feet at bottom.

The building of these piers commenced in December 1886 and by April 1887 had reached high-water level of the river. On financial grounds the works then were stopped, but were resumed in May 1888 and pushed on so rapidly that by the end of the following November they had reached to within 42½ feet of the top, which gives an average daily increase of over 6½ feet in height and 41½ cubic yards in volume. The mortar used consisted of 1 part Portland cement and 3 parts very fine sand.

On account of the rocky nature of the river-bed and because provision had to be made for rafting, a building-stage was inadmissible in the centre span, so it was decided to bridge over this by two cantilevers each 83 feet long, and a central girder of 111 feet in length resting between them. The length of the main-girders is 277 feet divided into ten equal bays by diagonal and vertical bracing, and the height throughout is 31 feet.

In the centre of each bay a cross-girder is fixed, which effects a saving in the material of the upper boom as well as in the girders which carry the sleepers—an idea taken from the Forth Bridge. The rails are laid 4½ feet below the upper surface of the top boom for the sake of safety.

Provision is made against lateral movement of the central girder both at the top and bottom of the joints connecting it with the adjacent cantilevers, which have their fixed support on the high centre piers and their other ends resting on roller-beds on the abutments of the bridge.

For hoisting up the materials two travelling-cranes are used, one on each top boom; and it is stated that one bay can be completed in three days, including the riveting for which two thousand three hundred bolts are required, and that while in bridge-building generally about 45 per cent. of the riveting is done in the shops and 55 per cent. *in sitû*, in this case 85 per cent. of the rivets will be driven in the shops and only 15 per cent. at the bridge site, thus securing faster, better and cheaper work.

The cost of earthwork and masonry is set down at £19,000 and of iron and wood at £32,000, or a total of £51,000; and since the area of cross-section of the valley is about 14,600 square yards, this gives a cost of £3 10s. per square yard as opposed to £3 for the Trisana, and £4 for the Garabit Viaduct.

The total weight of iron and other metal work in the viaduct is about 940 tons or $3\frac{1}{3}$ tons per linear yard.

A Plate accompanies the Paper, containing an elevation of the viaduct to a scale $\frac{1}{750}$, cross-section of a pier and detailed drawings of a bay and its connections.

W. H. E.

A New System of Examination for Iron Bridges.

By FIRMIN LARROQUE.

(La Lumière Electrique, vol. xxxiii. 1889, p. 230.)

Iron bridges are now made with such immense spans that it becomes daily of more importance to be assured of their safe condition. As yet few accidents have happened, but the metal is always deteriorating from the effects of change of stress, vibration, and oxidization. After the initial tests before the opening of a bridge it is usually considered sufficient if it be frequently painted, and if there be an absence of noticeable change of form. The elastic properties of the metal are gradually altered by the constantly changing stresses; this is imperceptible externally, and the Author considers the effects of vibration to be even more serious than those produced by direct bending. Proceeding to consider the case of an elementary bridge of one single girder, he says, when a rolling weight, travelling at a certain speed, crosses the girder it bends and vibrates; putting bending out of consideration, the girder may be considered as if made up of a great number of transverse laminæ separated by vertical planes; as the weight passes these laminæ in succession, waves of vibration travel from one end of the girder to the other, and remain distinct from one another, unless the weight move at the same speed as such waves are produced; so that it is clear that, when the weight has crossed the bridge, any given point has received the waves coming from all the separate laminæ, and, if a microphone be placed at such point, the waves may be transmitted electrically to a telephone. A record taken when the bridge is new may be compared with all future records, and the difference, if any, noted. Such difference would be an indication of deterioration. In order to compare the records they must be lasting; for this purpose the phonograph is used, and this is the key to the system. The Author has used three different methods; (1) A string, stretched by a small weight, was passed over a pulley, the spindle of which was fixed to the vibrating body; the string was then carried to a spiral spring, and thence to the diaphragm of a phonograph, the spring being used to lessen the length of the vibration; (2) An india-rubber ball, with a small weight placed upon it, was connected by tubing to a drum, one face of which was the diaphragm of a phonograph; both these methods are of little use when the distance between the phonograph and the vibrating point is great; (3) The vibrations are received by a microphone which transmits them to a telephonograph which registers them, and this method is suitable for any distance. In order that the length of time occupied in noting vibrations may be always exactly the same, a contact forming part of the circuit to the two instruments is placed at each end of the bridge, the first of which is closed by the passing body as it comes upon the bridge, the other opened as it leaves it. For comparison of different records, the Author prefers sight to hearing, and, for this purpose, has modified the phonograph as follows. In place of the diaphragm he uses a thin rectangular plate, fixed by one edge, and carrying at the other end a point on one side, and a very small mirror on the other, which latter reflects a ray of light on to a screen. The phonograph, if then made to travel parallel to the screen, produces a luminous zigzag line on it, and, if two instruments are used, and both are made to travel and revolve at the same speed, two records can be compared, or, one phonograph may be used in a fixed position, while a sensitized paper is made to travel in front of it in place of the screen. Any number of different tests may then be compared by photography. The Author has been able to discover, and to locate, hidden flaws in bridges by the above means, and the whole apparatus may be used for any number of bridges.

E. R. D.

An Apparatus for the Measurement of Strains in Ironwork.

By J. Deistler.

(Technische Blätter. Vierteljahrschrift des deutschen Polytechnischen Vereines in Böhmen, 1889, p. 17.)

This apparatus, the description of which is accompanied by illustrations in the text, was devised by the Author for testing the strains in various parts of finished iron structures. Although intended chiefly for tension and compression tests, it can also be adapted to the investigation and recording of other strains. Its action is based on the general principle that, within the limits of elasticity, the alteration of form in any bar is symmetrical at all points.

The apparatus consists of a round bar or rod with two clamps and a recording dial. The two clamps, which are generally used 3 feet 3 inches apart, though adjustable to other less spaces, are firmly fixed on to the bar or plate to be tested. The lower clamp is immovably connected with the testing-rod, which, however, works freely through a collar in the top clamp; this top clamp carrying the dial, upon which, to right and left respectively of a vertically-placed zero point, is a scale divided into spaces representing strains of 0·063 ton per square inch of either tension or compression. The scale is divided into four hundred of these divisions, *i.e.*, to a maximum of 25·2 tons per square inch.

The test-rod terminates by a micrometer-screw connection (by which the dial index can be adjusted to zero) on the centre of a hinged arm, the free end of which is connected with a hinged segmental rack-work and a central toothed-wheel which carries the needle or index-hand; so that the depression or elevation of the test-rod—corresponding to tension or compression of the bar, is communicated to a circular movement of the needle upon the dial. The proportion of elongation or compression can be set for different materials by means of an adjustment screw altering the fulcrum on the hinged arm; it is usually set for the modulus of elasticity of wrought-iron, but can be easily altered for testing steel, cast-iron, etc. The average results of many trials of the instrument have shown no greater variation than 0·4 per cent.

The apparatus can be used by varying clamps for flat or for round bars, plates, or any shape of ironwork; but care should be taken in case of deflection or curvature of the axis of the tested work that the test-rod is on neither the convex nor the concave side, as the result would be either exaggerated or understated on the dial. The successive deflections of the centre-line of a bolt when a nut is being screwed home can be seen very clearly by the indications on the dial.

P. W. B.

The Extension and Improvement of Libau Harbour.

(Centralblatt der Bauverwaltung, 1889, pp. 210 *et seq.*)

Libau, the most westerly Russian port on the Baltic coast, is situated, not far from the German frontier, on a flat sandy coast, and upon a strip of land between Lake Libau and the sea. It is one of the few Russian ports which are comparatively free from ice in the winter, and is therefore a position of considerable commercial value, especially since the railway communications with the interior of the country have been completed. The coast is occasionally closed up by drift-ice or by "snow-ice" (snow which freezes into a solid crust on the surface of the sea), but this can always be cut through by a steamer fitted with an ice-plough, as it does not accumulate to any great extent.

The old harbour is formed by the channel leading from the lake to the sea, into which it extends between two piers, lengthened about twenty years ago to 3,346 feet and 2,723 feet on the south and north sides respectively, so that the harbour is altogether about 6,230 feet long, with an average width of 350 feet. These two piers are formed of random rubble faced seawards with rough setts in cement, and on the harbour side with piling. The average cost of this work was about £45 per yard. At the same time the harbour was dredged to a depth of from 18 feet to 20 feet, the quay walls were extended, and two lighthouses built, and the bar at the mouth of the harbour was removed, so that a sufficient depth of water was obtained, and the commerce of the port greatly developed. In the course of two years, however, the channel had considerably silted up, so that the depth nowhere exceeded 16 feet; and although dredging was continually carried on, it was found impossible to attain a greater depth than 17 feet, and even this disappeared during the ensuing winter, so that early in the following spring the depth of water was not more than 13 feet, while the sandbank outside the piers had increased in width to the extent of 200 yards. A committee, appointed to examine the condition of the harbour and determine upon the works required for its improvement, occupied some years in its deliberations, so that the works decided upon could not be commenced before the early part of 1886.

The first work undertaken was the extension of the south pier,, which was lengthened by 3,914 feet, and carried forward in a line curving slightly to the northwards, into 30 feet of water. The northern pier, not yet completed, has a length of 5,692 feet, commencing at a point on the shore about 6,250 feet from the south pier, the clear water-way between the pier-heads being 525 feet. It was also decided to dredge the portion of the harbour outside and beyond the old piers to a depth of 24 feet, while the shore, by which so much silting has been occasioned, was faced for a considerable length by a sea-wall. The south pier is built of 17-ton blocks of masonry in cement-mortar, upon a random-rubble foundation. Beyond a depth of 21 feet of water this foundation is formed of larger blocks.

The cost of the harbour works, inclusive of the north pier, which is not yet completed, and which will when finished enclose a first-class harbour of refuge, is fixed at £1,185,000. A steel-built screw steam-dredger of 300 HP. has been provided, measuring 148 feet by 29 feet 6 inches by 12 feet 4 inches draught, and with a capacity of 325 cubic yards of dredged material; also a powerful steamer fitted with an ice-plough, and other implements for clearing any accumulation of ice in the harbour.

P. W. B.

The Port of Nicolaieff. By D. GNUSIN.

(Jurnal Ministerstva Putei Soobstchenia, 1889, p. 11 *et seq*)

This Paper extends through several numbers of the journal; the first part, besides a general description of the port, treats of the physical conditions of the locality, of meteorological data, of the currents and variations of the level of the water, the quality of the water, frosts, duration of time during which navigation is open, and the channel from Nicolaieff to the sea. The second part considers the port from a commercial point of view; and the third portion gives details of improvements which are being carried out to remedy the following defects:—

(1) The shallowness of the channel from Nicolaieff to the sea.

(2) The insufficient length of the quays.

(3) The incommodiousness of the town jetties, and the difficulty in getting vessels up to them.

(4) The incommodiousness of the ways leading from the town to the port.

(5) The absence of proper pavement on several roads leading from the business quarters of the town to the port.

(6) The want of additional railway-communication with the main line; and

(7) The absence of a harbour for barges satisfying the present conditions of the trade.

The channel from the port to the sea is to be deepened to a depth of 23 feet. For reasons enumerated by the Author, it has been decided to transfer the port to the Popoff creek, where the town jetties are now situated. The length of the quays is fixed at 550 sagenes (3,850 feet), their height above the level of the water at 1 sagene (7 feet), and their depth below water at 20 feet. The Author divides these projected improvements under two heads; the first, for which 1,630,000 rubles (£163,000) have been granted by the Imperial Treasury, includes the deepening of the harbour, the levelling of the port area for a width of 50 sagenes (350 feet) along the whole length of the quays, the construction of the quay walls, docks, &c. Under the second head, for which a sum of 200,000 rubles (£20,000), collected by a ½-copeck (0·12*d.*) town tax, is assigned, includes the erection of two railway- and three road-bridges, the lighting of the port, and the paving and laying down of two new approaches from the town to the port. The contract for these works was granted to Messrs. Boreesha and Maksimovitch. Details of the cost of the various works, excavations, &c., are given, and the Paper is illustrated by plans and drawings.

G. K.

Progress of the Works of Improvement in the Bilbao River.

(Anales de la Construccion y de la Industria, Madrid, 1888, pp. 68, 84, 101, 115, and 203.)

The *Anales* publishes in successive numbers the Annual Report of the Chief Engineer, Señor Evaristo de Churruca, containing a summary of the works executed in the river and harbour of Bilbao since the creation of the Board of Works (*Junta*) in 1877, with details of work done during the year 1887 at the expense of the local authorities; these being in addition to the extensive constructions by the numerous mining, railway, and industrial companies.

The exports (chiefly of iron ore) have risen during the last nine years from 1,195,422 tons to 3,921,164 tons; and the imports (chiefly of coal) from 144,977 tons to 473,270 tons, which large increase would have been impossible without the costly improvements which have been carried out during the same period. In 1878 the width of the channel over the bar at the entrance to the river was 70 metres, and the depth at low-water only 45 inches; the width has now been increased to 80 metres, and the depth, at the lowest tides, to 16½ feet, with the result that, whereas formerly vessels drawing 15 feet could only cross the bar at the highest equinoctial tides, vessels drawing 21 feet can now readily enter the harbour at high-water, and vessels of 2,000 tons can bring their cargoes up the whole length of the river, and discharge and reload at the quays of the town.

The works comprise extensive quay walls, docks, buoys, electric lighting, steam-cranes, a lighthouse, and a very large amount of dredging. The sea-wall at Portugalete has had an additional 890 yards added to its length, and the river is being provided with about 4,530 yards of loading quays on the right, and 2,000 yards on the left bank, the construction of which has been nearly completed. During the three years 1884–6, the river has been dredged to the extent of upwards of 906,000 cubic metres of sand and stone at a cost which, in the upper part of the river, exceeds 5*d.* per cubic metre, owing to the great distance which the sand and stones have to be carried, beyond the entrance of the port; and, in addition, 769,300 cubic metres have been raised by the same means during the construction of a large tidal basin, at a cost of 9*d.* per cubic metre. For a distance of 3½ miles from the mouth of the river to the anchorage at Desierto, the quays are illuminated at night by electric lamps during two hours before and two hours after high-water, and 1,598 vessels took advantage of this to enter the river at night during the year 1887.

The total cost of these works being estimated at £475,000, the expenditure by the Board during the year 1887 amounted to 1,957,287 *pesetas*, or about £40,000.

Further works of an extensive character have now been determined on, and a breakwater 1,500 yards in length at Abra, outside the entrance to the harbour, with a further defence opposite to it 1,190 yards long have been commenced. Between these walls there will be anchorage for large ships, the distance between the two being about 700 yards, and the depth of water 40 to 50 feet. The cost of these works is estimated at 30,597,309 *pesetas*, or £1,223,900.

O. C. D. R.

The Peculiarities in the Wear of Paving-Setts.

By — Fichtner.

(Deutsche Bauzeitung, 1889, p. 427.)

Referring to previous communications on the wear of road making materials, the Author states that while the reasons for the wear of wood-paving, asphalt, etc., have been clearly explained, he had failed to find, in anything already published on the subject, satisfactory reasons for certain singular deformations which take place in paving-setts. The arrangement of such setts may either be with the longer side at right-angles to the direction of the road, or diagonally inclined at 45° to the same. In the former case the length of the setts is usually about one and a half time their width, in the latter class of pitching the setts are generally larger and square in plan. By reference to diagrams, the Author explains the changes which gradually take place in level roadways and on inclines, the tendency being to induce a slight tilting of the bed of each stone, which in time causes the sett to lose its verticality. Traffic passing from left to right causes the right edge of the stone to rise, or the left edge to sink, and *vice versâ*, leading eventually to a saw-like formation of the road-surface. In sharp inclines, such as the ramps of bridges, etc., where the setts are placed so that their joints are originally at right-angles to the inclination of the ramp, the same alteration in position takes place. The Author believes these changes to be produced by the wheels of vehicles, which, after passing the soft joint, give a slight rap to the edge of the stone first encountered, and this hammering causes this edge in time to drop. The changes could scarcely be effected by the horses' hoofs, as, on descending ramps, where the horse is to a certain extent being pushed before the vehicle, the same tendency can be observed. The alteration in the surface of the roadway can best be noticed when the street has recently been watered, and when the sun is shining along it. In this case, looking towards the sun, a series of dark lines will be seen marking the joints across that part of the road traversed by vehicles from right to left, the portion of the roadway traversed from left to right being bathed in light or *vice versâ*. The smaller the width across the setts, the less is this tendency to become displaced. The Author gives a design for a frame 3½ metres in length, containing a section of roadway, pitched with setts of a given size, and furnished with an arrangement beneath for recording graphically the changes which are produced in the position of the paving-setts. This apparatus could be inserted in a public thoroughfare, and would be useful in determining, by practical experiment, the best sizes and shapes for paving-setts, and the most durable methods of bedding them.

G. R. R.

Wave-Power Pump.

(Engineering News, New York, September 7, 1889.)

A wave-power pump has just been put in operation at Ocean Grove, New Jersey, to supply water for street-sprinkling. The device is the invention of N. O. Bond, of Fairfax, Virginia. A pier was built out into the surf, and on the seaward side were hung eight gates, swinging on a horizontal rod along their top. Each gate is 13 feet wide, and its lower edge is immersed about 2 feet at low tides and 7 feet at high tides. A rocking arm attached to the gate is connected by a rod to a force-pump with horizontal cylinder. The water is forced to a tank about 40 feet above, whence it is drawn as needed by the sprinkling-carts. Press reports state that on the 26th of July, when two of the gates were first put in operation, 40,000 gallons of water were pumped into the tank. The length of time taken to do this is not stated; but, estimating it at twelve hours, each gate would have developed from 20 to 25 HP. But *Engineering News* thinks it is hardly likely that a gate of that size would prove so effective an engine. Most probably the tank to which the water was pumped was 40 feet away from, instead of 40 feet above, the sea. This supposition is corroborated by an examination of the New Jersey map, which fails to show any elevation in or near Ocean Grove more than 20 feet in height.

Duty-Trials of Pumping-Engines. By GEORGE H. BARRUS.

(Journal of the Association of Engineering Societies, New York, 1889, p. 365.)

The Author considers that a standard method for testing steam pumping-engines is most desirable. Yet, although a trial is particularly necessary for this class of engine, the test is usually left to the discretion of the experimenter, and no recognized standard exists. What constitutes a duty-trial is still an open question. Sometimes it is the number of lbs. of water elevated 1 foot by 100 lbs. of coal; sometimes it is this quantity plus the work equivalent to the friction of the delivery-main. Some engineers reckon the volume of water displaced by the plunger; and some the number of foot-lbs. of work done. The duty-trials as now returned are very confusing, and the following points differ in most of them, viz., the amount of steam evaporated by 100 lbs. of coal; the percentage of ash in the various coals; the measurement of the water from the pump; the moisture in the steam; and the temperature of the water and the steam.

The main object of a test-trial of a steam pumping-engine should be to determine the economy of the engine; that is to say, under what circumstances it will perform the greatest amount of work with the least expenditure of fuel. A standard method should embrace the five following points:—

I. To enable one engine to be compared with another.

II. To help the engineer to compare his engine with a given competing type.

III. To furnish the purchaser with the actual facts, and the means of knowing the economy of different forms of engine.

IV. To provide engineers with various data for making improvements.

V. To establish an authoritative standard for the use of engineers and purchasers, by specifying the methods to be followed in any contracts.

In order to make this method applicable to every pumping-engine, which is the main object of the Author, it is first necessary to establish a unit of measurement suitable to all circumstances. The unit usually adopted, viz., 100 lbs. of coal, is undesirable, because it varies so much with the evaporative power of the particular coal used. To avoid this difficulty, some engineers reckon the quantity of steam consumed, using a unit of steam. But this is also limited in application, and unfit for the purposes of a standard. Care must always be taken to give the temperature of the feed-water in each case, as without it the comparison would be erroneous, and any new system should take this into account. The best unit of measurement, therefore, is the heat-unit, which is independent of the boiler, the steam generated by it, and the coal consumed. The heat-quantities are the only true basis on which to determine a standard for the performance of a steam pumping-engine.

This involves no great departure from the ordinary unit of 100 lbs. of coal. The heat-unit may be calculated as the amount of heat produced by 100 lbs. of good coal, burnt under favourable conditions. Thus, if $11\frac{1}{4}$ lbs. water are evaporated at 212° by 1 lb. of coal—a good average performance for both boiler and coal—$11\frac{1}{4}$ lbs. $\times$ $966 = 10{,}867 \cdot 5$ thermal units for 1 lb. of coal. Therefore the present unit of 100 lbs. of coal may be expressed by $10{,}867 \times 100 = 1{,}086{,}750$ thermal units, or in round numbers, 1,000,000 thermal units. This is the unit proposed by the Author as a standard for duty-trials of pumping-engines.

The heat thus computed should be taken as the total heat of all the different parts of the engine, including donkey feed-pump, steam-jackets, independent air-pumps, and any other accessory apparatus. These accessories being a necessary part of the engine equipment, the same economy should be employed in their construction as in that of the engine itself, and the heat they require ought to be comprised in the total heat consumed by the engine.

The heat-unit having been determined on, the next point is the consideration of the work done. Here there are two factors; A, the number of lbs. of water pumped; and B, the height in feet to which it is raised.

A. The water may be measured in three ways:—(1) Into a reservoir; (2) over a weir; (3) by calculation from the pumps. The first two methods have the disadvantage of being costly, and difficult to apply in most cases. The Author therefore considers the third as by far the most practicable, viz., that of computing the plunger displacement. Due allowance must of course be made for leakage from the plunger and the valves. Care must also be taken to calculate the loss from the return of water through the valves at the end of the stroke, and from the introduction of air.

B. The lift in feet should be reckoned from gauges placed on the pressure and suction sides of the pump. There are now, for the standard mode of expressing the amount of work done, the weight of water computed from plunger displacement, corrected for leakage and the presence of air as pointed out, elevated to a height corresponding to the pressure shown by a gauge attached to the force-main, plus the head corresponding to the vacuum shown by a gauge attached to the suction-main (or minus this head if the gauge shows pressure instead of vacuum), plus the vertical distance between the centres of the two gauges, no allowance being made for friction of the water passing through the passages and valves in the pump.

In accordance with the views of the subject thus laid down, the duty of all engines would be expressed by the following formula:—

$$\text{Duty} = \frac{\text{Foot-lbs. work done}}{\text{units of heat consumed}} \times 1{,}000{,}000 = \frac{[C\,V\,w\,N - L] \times [H + s + h]1{,}000{,}000}{\text{units of heat consumed}}.$$

V = volume of piston displacement, one stroke, cubic feet.

w = weight of a cubic foot of water.

N = number of strokes during the trial.

H = head in feet corresponding to the indication of the pressure-gauge (force-main).

h = head in feet corresponding to the indication of the vacuum-gauge (suction-main).

[This is a minus quantity where there is a head of water on the suction-main, and a pressure-gauge is used.]

s = vertical distance in feet between the centres of the two gauges.

L = total leakage of the plungers during trial, estimated from results of the leakage-test with the pump at rest.

C = correction for air admitted into the pump = proportion of the stroke during which the pump is subjected to the full discharge pressure measured from the indicator diagram.

The Author proceeds to illustrate the foregoing remarks by three examples, two with jacketed compound engines, and one with a jacketed compound direct-acting duplex engine.

The adoption of the proposed method of displacement measurement of the quantity of water pumped does not stand in the way of actual measurement by a weir, or by other means where opportunity presents itself for such work. No objection can be raised to a contract which requires a weir-test to be made, for the more this class of data is obtained the better; but this test can be regarded as furnishing supplementary data, the main results being referred to the standard of displacement measure.

To cover the foregoing requirements in the framing of a contract, the guarantee as to the performance of a complete plant may be expressed in the following terms: "The engine shall perform a duty equivalent to not less than (A) foot-lbs. of work for each one million thermal units of heat consumed, and the difference between the actual delivery by weir measurement and that calculated from plunger displacement shall not exceed (B) per cent. Furthermore the boiler shall supply one million thermal units of heat to the engine on a consumption of (C) lbs. of (D) coal. The duty-trial is to be conducted and the results are to be computed in accordance with the standard method of conducting duty-trials, determined upon by (the authority named). If one contractor furnishes the engine, and another the boiler, separate guarantees will be made, the individual requirements being the same as in the case of the complete plant."

The Author next lays down a standard method of conducting duty-trials. He gives minute directions for carrying them out, and advocates the use of two tanks, one tank above the other, for measuring the feed-water. The boiler as well as the engine should be tested. The trial should be made in accordance with the rules for a standard method recommended by the Committee on Boiler-Tests of the American Society of Mechanical Engineers. This method, briefly described, consists in starting the test with a new fire lighted with wood, the boiler being previously heated to its normal working degree; operating the boiler in accordance with the conditions determined upon; weighing coal, ashes, and feed-water; observing the draught, temperatures of the feed-water and of the escaping gases, and such other data as may be incidentally desired; determining the quantity of moisture in the coal and in the steam; and at the close of the test hauling the fire, and deducting from the weight of coal fired whatever unburned coal is contained in the refuse withdrawn from the furnace, the quantity of water in the boiler, and the steam-pressure being the same as at the time of lighting the fire at the beginning of the test.

The engine-test should continue at least ten hours.

Observations of the length of stroke should be made every five minutes; of the water-pressure gauges every fifteen minutes; of the remaining instruments, such as steam- and vacuum-gauges, thermometers in the pump-well, and in the feed-pipe, thermometers showing temperature of the engine, the boiler-room, and the outside air; thermometers in the flue and in the steam-pipe, barometer, &c., every half-hour; indicator diagrams should be taken every half-hour from the steam-cylinders and water-cylinders.

Indicator-pipes and connections used for the water-cylinders should be of ample size, and as far as possible free from bends: $\frac{3}{4}$-inch pipes are preferred, and the indicators should be attached one at each end of the cylinder. It should be remembered that indicator-springs, which are correct under steam, are erroneous when used for cold water. When steam-springs are used, the amount of error should be determined, if calculations are made of the indicated work done in the water-cylinders.

B. D., Jun.

Godillot's Step-Grate Furnace for Burning Poor Fuels.

By — Brüll.

(Bulletin de la Société d'Encouragement, June 1889, p. 289.)

Mr. Godillot's furnace is designed for utilizing inferior fuels, as, for instance, saw-dust, wood-chips, refuse of sugar-houses, flax refuse, wet tan, chips of dye-woods, and refuse bark of oak and chestnut tree used for the extraction of tan. Several of these combustibles contain upwards of 60 per cent. of water.

The system is shown in its application to an ordinary French boiler. The furnace is constructed in front of the boiler, below the level of the floor, in the manner of an ordinary gas-producer. But the novelties are two-fold. First, there is the grate, which is of the form of half of a frustum of a cone—semi-circular in plan—formed with semi-circular bars in step fashion, expanding from the top towards the bottom, like the steps of a semi-circular stair. The fuel is fed mechanically upon a small platform forming the summit of the grate, whence it falls spontaneously and distributes itself equally over the whole of the grate, landing on a horizontal surface at the bottom.

The supply of fuel is continuous, and is effected by means of a cast-iron helix, which revolves at a low speed, at the base of a hopper containing the fuel. The core of the helix is conical, so that the capacity increases, and the helix clears itself freely, as the fuel advances towards the grate, whilst it receives fresh fuel over the whole of its length. The fuel is first dried, then heated, then inflamed, for which purpose air is supplied between the bars of the grate at all levels.

From the results of two days' trials with two French steam-boilers, having each 1,075 square feet of heating surface, the following particulars are given:—

Duration of Trial		Eleven Hours.	Twelve Hours
Wet chips consumed	lbs.	12,153	31,963
Loss of weight after sixty hours' drying . . .	per cent.	62·3	62·3
Water contained in the chips	lbs.	7,350	19,910
Weight of the chips dried	,,	4,803	12,053
Feed-water consumed	,,	18,348	47,478
Temperature of water	Fahr.	77°·5	
Water evaporated per lb. of chips, wet . . .	lbs.	3·19	3·19
,, ,, ,, dried . . .	,,	8·45	8·45
Wet chips consumed per square foot of heating-surface per hour	,,	0·51	1·23
Weight of steam per square foot of heating-surface per hour	,,	0·74	1·79
Average temperature of the burnt gases leaving the boilers	Fahr.	243°	243°

D. K. C.

Water and its Cost. By — KINDERMANN.

(Wochenschrift des österreichischen Ingenieur- und Architecten-Vereins, 1889, pp. 163, 164.)

The above-named subject is discussed in this Paper mainly with reference to the requirements of Vienna, and it is pointed out that hitherto the determination of the quantity of water, to be provided for a town per head of population, has usually been deduced without reference to its cost and also without considering the purpose for which it is required, and this materially modifies the cost; for example, while good and pure drinking-water may have a value approximating to that of mineral waters, that required for flushing closets and drains or watering streets, should be of the lowest price possible; and while on the one hand the quantity of drinking-water per head will vary very slightly, there is no maximum limit to the supply for watering streets or flushing drains—the more the better being a generally accepted rule.

For small towns an abundant supply may be readily available, and the consumption therefore very large; in this case the cost of the water will be reduced if the distance of the source of supply be small, and the same will apply to large towns which draw their water from neighbouring rivers or lakes; but nevertheless the water may be too dear for certain industries which will then have to undertake their own arrangements for obtaining their water direct from the soil, and thus avoid compulsory prices as in Berlin.

In Vienna the source of supply is the Hochquelle, and this water could only be delivered in the suburbs at a cost of about four times that which is desired, or in other words, the quantity per head could only be one-fourth of that considered necessary, hence the importance of the question of cost. The system now in use in

Vienna may be technically termed the single-distributing system, as it supplies only one quality of water for all purposes, as opposed to the double system which provides two different kinds of water. If the former system then be maintained throughout, any increase of water required must be drawn from the Hochquelle, or if this source be not sufficient, from other springs furnishing water of the same quality. Hence in this case the quality of the water is the main consideration, and its price a secondary one; but if a double set of mains be laid, the additional supply required should be obtained at as cheap a rate as possible, and the naturally-filtered water of the Danube, that from the Wien Thal, the Fischa-Dagnitz, the Neustadt Steinfeld, and other similar sources, are mentioned as suitable for the purpose. If therefore the demand for drinking-water be limited to the Hochquelle, and service-water be obtained elsewhere, all possible requirements for the future will be met and the quality of the water will be maintained.

The Author concludes his Paper by stating that in his opinion the future water-supply of Vienna and suburbs will best comply with the requirements of sanitation if a double set of pipes be laid down, which arrangement will on the one hand preserve the purity of the Hochquelle, and also meet any possible additional wants. Another desideratum is the speedy removal of excreta from the houses, for although Vienna has an excellent system of flushing the drains, water-closets are not compulsory, and therefore the flushing system is incomplete. For this an abundance of water is absolutely necessary, which can only be provided by the second service-main.

W. H. E.

Wiener-Neustadt Water-Supply.

(Wochenschrift des osterreichischen Ingenieur- und Architekten-Vereins, 1889, p. 248.)

The water is drawn from deep springs, and conveyed by a concrete tunnel or conduit 4·36 miles in length right across the Steinfeld plain (1¼ mile south of Wiener-Neustadt). The tunnel is 9·8 feet wide in the clear, and of the same height up to the springing of its semi-circular top; the floor or sill varies from 49 to 92 feet below the surface of the ground, and is on an average over 13 feet below the deepest subsoil water-surface. The side-walls are about 4 feet thick, and the arch at the crown is 2 feet, and the walls are at intervals braced together by stiffening pieces 1·64 foot high, and 3·28 feet wide, built on the floor of the tunnel.

The fall from west to east is 3·28 feet in a length of 4·07 miles, and a similar fall is given to the eastern branch which is 763 yards long. The water is conveyed into a deep reservoir at Wiener-Neustadt, which is divided into two parts; the discharge of water from the tunnel into the first division will be regulated by sluices, and from the first into the second by a weir or overfall in the partition-wall so arranged as to admit of a discharge of 264 gallons per second, or 22,809,600 gallons a day. The distributing main is 29½ miles long, and formed of cast-iron pipes of diameters varying up to 4·4 feet, and 2 inches thick, and will lead the water into a reservoir at Rosenberg, near Hietzing; while a branch 2·8 miles long leads to a reservoir at Wienerburg; and the main reservoir, which will be fed from that at Rosenberg, is established at Neu-Gersthof.

Branches to the villages along the line of the tunnel, and as far as Klosterneuburg, Floridsdorf, &c., are contemplated, which will convey the water by gravitation, but for higher-lying villages the water will be pumped up.

The principal high-pressure reservoir will be built at Schafberg, near Dornbach. The distributing-pipes will be 325 miles long; the smallest pipe for conveying water by gravitation will be about 3 inches in diameter, and under pressure 4 inches, and the cost of water in these two cases will be about 1*d.* and 1¼*d.* per 100 gallons respectively.

W. H. E.

The Water-Supply of Tôkiô. By Adolf Schwarz.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereins, 1889, p. 259.)

Tôkiô (formerly called Yedo), has a population of one million two hundred and ten thousand, and when first it was made the capital of the Empire the supply of drinking-water was bad in quality and deficient in quantity. To remedy this, a succession of projects have been carried out from time to time, the first of which, dating back as far as 1620, consisted in taking water from three lakes west of Tôkiô (situated at elevations of from 120 feet to 140 feet above sea-level), and leading it in wooden pipes to the central quarters of the city, Koishi-Kawa, Kanda, and parts of Niphon Bashi, the quantity so supplied amounting to nearly 17,000,000 gallons daily.

The second project was carried out in 1652 by damming up the river Tamagawa, and leading the water in an open canal 27 miles in length, to Yotsuya the western boundary of the city, and thence supplying the populous quarters in the south and west with nearly 24,000,000 gallons per diem. The level of the water at the take-off is about 400 feet above the sea, and the canal follows the course of the valley for its whole length to avoid heavy earthworks, and varies in breadth from 21 feet to 29½ feet. By these two projects a sufficient supply is provided for four hundred thousand people. A third scheme was opened out in 1882, under which the water was taken from the Tamagawa canal and led to the northern quarters of the city Kioshi-Kama and Hongo, the daily supply being 1,330,000 gallons.

The distributing pipes generally are of wood, formed from hollow trunks of trees if under 6 inches in diameter, but if larger the section is rectangular with thickness varying from 2¼ inches to 6 inches. To resist great pressure, the pipes are hooped with iron, and water-tight joints are made with tree bark. Stone conduits are also used, and the lengths of wood and stone respectively are 100 miles and 4½ miles.

Where there is a sudden and great change in level or direction, a reservoir-cistern is built with sides varying from 2½ feet to 6 feet in length according to the section of the discharging pipes, and these reservoirs also serve to measure the quantity and test the quality of the water.

The water is not led direct to the houses, but to wells, and of these there are 7,765, of which 2,935 belong to the Tamagawa, and 3,704 to the Kanda scheme.

Nearly the whole population of ninety thousand on the left bank of the Sumida river is supplied with water from neighbouring rivers and the surplus of the three schemes above described, the amount so supplied being 77,000 gallons daily, but this quantity is supplemented by numerous common and artesian wells.

W. H. E.

The Influence of Ventilation on the Micro-Organisms in Suspension in the Atmosphere. By Dr. RICHARD STERN.

(Zeitschrift für Hygiene, 1889, p. 44.)

Notwithstanding the numerous investigations that have been made to determine the numbers of germs present in the air of dwellings, and the effects of disinfectants upon such germs in sick rooms, &c., the Author states that no attempts have hitherto been made to ascertain how far it is possible, by means of ordinary ventilation, to expel the micro-organisms from an enclosed space, and to disinfect the air by this simple means. To endeavour to elucidate this question, the Author, on the suggestion of Professor Flügge, undertook a series of experiments at the Breslau Hygienic Institute. These experiments were directed to ascertain further the effect of steam upon germs floating in the atmosphere, and to test how far it might be possible, by means of air-currents due to ventilation, to remove germs from floors, carpets, and clothing. The room used for the tests was situated on the third floor of the house; it had two doors and two windows, and contained 85·41 cubic metres. The arrangements made to seal the openings and to admit and exhaust the air are described, and the mode of generating the air-currents by gas-jets and water-sprays is explained; the maximum yield of the ventilation was 2,250 cubic metres per hour, equivalent to a renewal of the air in the room twenty-seven times, but the currents could be controlled and reduced to any extent. Experiments were made with very fine dust, specially prepared, and obtained from schools and factories; this dust was impregnated with the spores of the *Bacillus megatherium*, because this bacterium, on account of its unusual size, can readily be distinguished from others under the microscope. Other experiments were made with the spores of *Aspergillus niger* alone. The dust was disseminated through the chamber by means of a spray-producer and a Japanese fan. The spores were collected on a sand filter on the plan proposed by Petri, and cultivated on a mixture of agar-agar and gelatine. Tables of the various results are appended, and the Author sums up the experience gained as follows:

(1) In still air the germs sink rapidly to the ground; when school-room dust is used, the atmosphere, even in the course of one hour and a half, becomes nearly germ-free. When still finer particles are used (such as the finest wool-fibre, rag-dust, and mildew spores), a longer time is of course required.

(2) With ordinary ventilation, corresponding to a renewal of the air from once to thrice in the hour, the air does not apparently become free from germs more rapidly than it would do by simple deposition alone (there is one slight exception in the case of a descending current in the winter time).

(3) A more rapid rate of air-renewal, but such as is scarcely practicable without giving rise to draughts, gradually increases the influence of the ventilation on the suspended germs. The lowest limit at which such an effect begins to take place would seem, from the experiments, to be such a rate as would renew the air from six times to seven times in the hour.

(4) A rapid and complete removal of the germs from the atmosphere of dwellings can only be effected by a violent draught.

(5) No considerable number of germs can be detached from the surface of floors, carpets, furniture, clothing, &c., even by causing the room to be traversed by strong draughts.

(6) The generation of steam does not effect the speedy and complete deposition of suspended germs, and it only hastens the same to a slight extent.

G. R. R.

The Physical Action of Precipitants upon Micro-Organisms present in Water. By BRUNO KRÜGER, of Jena.

(Zeitschrift für Hygiene, 1889, p. 86.)

The fact that the germs, believed to be the active agents in producing certain diseases, are capable of existing for some time in water has caused the bacteriological examination of rivers, streams, and lakes to assume new interest and importance, more especially, too, because it is from these sources that the water-supply of numerous towns is derived. Investigations have shown that more carbonic acid had been generated in the space to be tested, the evolution of the gas was stopped, and subsequently, and also after a given time had elapsed, the volumes of the gas present in the air were determined; in the other, a supply of the gas of known volume was evolved continuously, and this factor was used as a basis of comparison with the other ascertained analytical data. This latter plan was the one used by the Author, but he made certain changes in the process which he explains by the aid of a diagram. The chief point was the employment of the fluid, compressed carbonic acid gas, now everywhere procurable, as the source of supply. Full details are given of the tests and of the results obtained. The Author states that the current price of the liquid gas in Berlin is but 1 mark per kilogram (5·4*d.* per lb.).

G. R. R.

The Disinfecting Properties of Creosote.

By Dr. CARL FRANKEL, of Berlin.

(Zeitschrift für Hygiene, 1889, p. 521.)

Laplace had first shown that the disinfecting power of solutions of corrosive sublimate and phenol is very considerably increased by the addition of acid, and he demonstrated the fact that the so-called 25 per cent. carbolic acid, which is inert and comparatively useless for disinfecting purposes owing to its insolubility, is, when treated with sulphuric acid, converted into a powerful disinfectant, soluble in water and watery fluids. The Author had occasion to repeat the experiments of Laplace, and used for this purpose a mixture of equal weights of raw (25 per cent.) carbolic acid and pure concentrated sulphuric acid, slowly added to one another with due precautions, to avoid excessive heating. In first making the mixture, without these precautions, great heat was evolved, but when care was taken to cool the vessel, and to add the sulphuric acid slowly, a sulpho-carbolic acid was produced, which was tested separately to that which had become heated. Both samples were tested as 5, 4, 2, and 1 per cent. solutions, and, for the purpose of comparison, similar solutions of pure crystallized phenol and of concentrated sulphuric acid were examined in a similar way. The test-objects were anthrax spores dried on to silk threads, and the cultures took place at blood-heat in prepared bouillon. The results are set forth in a Table, and show the marked superiority of the mixture prepared cold to that which was allowed to become heated. The general results differ in many respects from those obtained by Laplace, and the Author considers that this may be due to the nature of the anthrax spores used, for it is now known that certain varieties of these spores have much greater powers of resistance than others; and a mode of testing the powers of endurance of such spores is proposed, namely, by the period they can resist a

5 per cent. solution of pure crystallized phenol. Those spores which can survive a twenty to forty days' exposure to such a solution to be classed as "highly resisting"; those withstanding an exposure of from ten to twenty days as "moderately resisting"; and those destroyed in less than ten days as "weakly resisting" spores. The reason of the superior action of the cold preparation of the acid mixture is discussed, and is considered to be due to certain highly poisonous compounds described by the Author.

G. R. R.

Experiments on the Practical Disinfection of Excrementitious Substances. By Dr. S. von Gerlóczy, of Pesth.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1889, p. 433.)

These experiments were carried out in the course of the past year at the Pesth Hygienic Institute, in order to test the real values of the various substances employed as disinfectants, concerning which much difference of opinion had been expressed. The Author divided the matters to be disinfected and deodorized into five groups, viz.:—(1) Night-soil from cess-pits; (2) liquids from sewers; (3) solid contents of street gulleys; (4) dry road-scrapings; and (5), fresh excreta of patients suffering from acute diarrhœa and typhoid fever. The disinfectants used were:—(1) corrosive sublimate; (2) iron sulphate; (3) zinc sulphate; (4) copper sulphate (for comparison); (5) crystallized carbolic acid; (6) raw carbolic acid (two descriptions of which are obtainable—that employed by the Author, known as 50 to 60 per cent. solution, actually contained 18·7 per cent. of carbolic acid); (7) carbolized lime, commercially known as 5 per cent., but yielding on analysis 2·1875 grams of carbolic acid per 100 grams; (8) creolin; (9) *a*-oxynaphtoic acid. On the score of their extreme cheapness, the Author used also: (10) raw concentrated sulphuric acid; (11) freshly slaked lime; (12) boiling water; (13) hot and cold solutions of wood-ash lye (specific gravity of the lye 1·037, equivalent to 4 per cent. of carbonate of potash); (14) solution of common salt, containing 26·1 per cent. of salt. Specimens of the disinfected materials were withdrawn on a platinum needle, and introduced into warm fluid peptone-gelatin. The cultivation took place both at ordinary temperatures, and also at a temperature of from 35° to 37° Centigrade.

The specimens were examined at intervals of twenty-four hours, forty-eight hours, and from three to four days after treatment.

Group I. *Night-soil.*—Samples for experiment were obtained from a night-soil-removal contractor; 100 grams were placed in a glass vessel, and treated with weighed quantities of each of the disinfectants enumerated, in various proportions. The results are set forth in detail, and they show that a practical disinfection of night-soil is all but impossible, as even 2·5 per cent. of corrosive sublimate is insufficient to render it germ-free; this quantity would entail a cost of 150 gulden per cubic metre (£9 11*s.* 1*d.* per cubic yard). Complete sterilization resulted from the use of a 4 per cent. solution of copper sulphate, and it would appear from this that with this material, 1 cubic metre of night-soil could be disinfected at a cost of 12 gulden (£1). For the purpose of deodorization, the use of raw carbolic acid may be regarded as successful.

Group II. *Sewage-water.*—Was treated with the foregoing disinfectants in a similar way, full details of the experiments being given. Here again the Author draws attention to the extraordinary value of copper sulphate; a solution of 1 per mille sufficed to destroy all germs, and rendered the liquid clear and inodorous.

Group III. *Sludge from gulleys.*—The series of experiments recorded shows the extreme difficulty of disinfecting thoroughly this substance. For deodorization, carbolized lime in moderate quantities sufficed, but the Author recommends the use of raw carbolic acid diluted to 1 per mille.

Group IV. *Street-sweepings, &c.*—Owing to the last cholera outbreak in Pesth, the authorities ordered that carbolized lime should be freely used in the dwelling-houses, and they caused it to be strewn along the roads, against walls, under doors, and over gulley-holes. The Author therefore carried out special experiments to test the value of this treatment, and to ascertain how far it might be possible to practically disinfect road-sweepings. Treated with the foregoing disinfectants it became manifest that complete disinfection was out of the question. Even where thoroughly soaked with solutions of corrosive sublimate, copper sulphate, &c., the road-dust was far from sterile; nor did experiments with respect to the strewing of carbolized lime yield satisfactory results. The advantages of this mode of disinfection are illusory.

Group V. *Disinfection of excreta.*—In certain cases it becomes of the utmost importance to thoroughly and rapidly sterilize the dejections of patients. The excreta used for these experiments were in all cases diluted with three times their weight of water. All the various disinfectants were tried in different proportions, and the results of the experiments are recorded. The conclusions arrived at by the Author are: that a strong solution of copper sulphate should be used, at least 1 gram of the disinfectant being added to 100 cubic centimetres of excreta; but still better results arise from the employment of thrice their weight of boiling lye (2 parts of water to 1 part of wood-ashes). Milk of lime (1 part of slaked lime in 20 parts of water), used in the proportion of $\frac{1}{5}$ to $\frac{1}{10}$ of the weight of the excreta, likewise disinfects cheaply and well.

G. R. R.

The Dessendier Recording Photometer. By A. Palaz.

(La Lumière Électrique, vol. xxxiii. 1889, p. 407, 3 woodcuts.)

The Author states that this instrument fills a long-felt want in photometry. It depends for its action upon the principle that if a mixture of equal volumes of hydrogen and chlorine be kept in the dark no change takes place; but when exposed to light the gases combine to form hydrochloric acid, and this can be absorbed by a solution which will rise in height and occupy the space vacated by the gases. As the quantity of hydrochloric acid formed is proportional to the quantity of light received, a scale can be made; but it is first necessary to find the relation which holds between the effect of light upon the mixture of gases and that upon the retina, as the eye is the ultimate judge of the light. This relation is difficult to determine with accuracy, as the effect upon the retina depends to a large extent upon the colour of the light as well as upon its intensity, and if the eye be dispensed with as judge, the simplest method would be to use a selenium cell, and to measure the variations of current in its circuit which are produced by variations in the intensity of the light being experimented upon.

The instrument is composed of a vertical glass tube for holding the gases, which are obtained by electrolysis of hydrochloric acid of a density 1,148; the tube is closed at the top, and provided with a cock at the bottom, having a passage as large as the interior of the tube; the cock, as well as a tubular prolongation below, is made of black glass. Above the cock is an exposing chamber, through which the gas-tube passes, and which is fixed to a support, and has its sides and bottom blackened, and a transparent cover. An iron tube, with closed end, covers the gas-tube and passes through a screwed stuffing-box in the top of the chamber. When screwed right down, no light can reach the gas; but, as the iron tube is screwed up, a ring of the gas-tube is left free to the action of any light upon the transparent cover of the exposing-chamber. The covering-tube then remains stationary. The gas-tube, with the cock and black tube, which is filled with a solution for absorbing the hydrochloric acid gas as it combines under the action of the light, has a chain attached to it which passes over certain pulleys, and has fixed to it a pointer and the pencil which draws the record upon a sheet of paper fixed in the ordinary way to a cylinder moved by clock-work. Attached to the bottom of the vertical black tube is a flexible pipe containing mercury, and bent in the form of the letter U for the purpose of maintaining a constant pressure on the gas and liquid in the vertical tube; into the unattached end of the mercury-tube drops a small rod, which, when in contact with the mercury, closes the circuit for a small battery working an electro-magnet, which brakes one of the pulleys round which the chain passes. In beginning an experiment, care must be taken not to use a bright light, lest an explosion of the gases should take place; when the light acts on the exposed ring of the gas-tube, the gases combine, the absorbing liquid rises to take up the space, the mercury in the free end of the flexible tube falls, the battery circuit is broken, the brake ceases to retain the pulley, and the weight of the vertical tube containing the gas and liquid causes it to descend, drawing the chain down and raising the recording pencil; the mercury again rises in the flexible tube, the battery circuit is completed, the brake applied, and the motion ceases; the gas-tube is again exposed for the same distance as before, and the action proceeds. The instrument may be exposed to strong sunlight with safety; and, of course, the stronger the light, the more quickly do the mechanical movements succeed each other. The Author considers that it will be necessary to find the law according to which the results vary for light emitted by the sun, gas, incandescent and arc lamps, as they will be very different; but, if the instrument be previously standardized, very valuable data may be obtained, and it should be of much service in meteorology for recording variations in sunlight during the day.

E. R. D.

Railway from Ciaño-Santa Ana to Soto del Rey.

(Anales de la Construccion y de la Industria, Madrid, 1888, p. 157.)

The Asturian coal-fields are among the most extensive in Europe. They attracted much attention nearly half a century ago, and the first railway constructed in Spain was built at that period with the object of giving an outlet to the Atlantic Coast at Gijon to that portion of the field, 100,000 acres in extent, which is situated on the banks of the River Nalon, at Sama de Langreo and Ciaño-Santa Ana; besides which a turnpike road conducts from Sama to Oviedo, the capital of the Province of Asturias. The railway was indifferently well constructed, with a comparatively narrow gauge, and two inclined planes worked by stationary engines; but a large amount of capital was attracted to the district, iron-works and other industries were established, and for many years Langreo was very prosperous.

Meanwhile, further to the south, on the banks of the River Mieres (which runs into the Nalon at Soto del Rey), at the town of Mieres and at La Pola de Lena, English and French capitalists acquired equally valuable coal-mines, and also erected iron and steel and other works. These existed for many years without any railway communication, but when the trunk line which connects the Asturian seaports of Aviles and Gijon, through Oviedo, with Leon and Castile, across the elevated pass of Pajares was finally laid out about fifteen years ago, the direction given to it was down the Mieres valley, and Langreo was left out in the cold.

The result has been that there has been a very serious diminution in the metallurgical production, other industries languish, large numbers of men are thrown out of work, and many of the mines have been closed. The Langreo district produces annually 300,000 tons of coal, 15,000 tons of iron, 25,000 tons of timber, 20,000 tons of agricultural, and 15,000 tons of other kinds of traffic; 3,200 men are employed in the coal mines, 1,350 in the iron-works, and 1,870 in other industries; and the *Anales* publishes appeals to the Government from numerous local authorities urging the necessity of a subvention being granted towards the construction of the railway from Ciaño-Santa Ana to Soto del Rey, which would connect this important industrial centre with the trunk line, and give an outlet for its produce to the interior of the country, as well as to the capital of the province, and to the seaport of Aviles.

O. C. D. R.

Railway from Zafra to Huelva.

(Anales de la Construccion y de la Industria, Madrid, 1888, p. 329.)

Under the heading of "How railways ought to be worked," attention is called to this line, which has been constructed with English capital, and which was opened to traffic a few months ago, by the owners of the very extensive Rio Tinto copper mines. Besides connecting these mines with the Port of Huelva, it extends in the opposite direction to the centre of the corn-producing province of Estremadura, at Zafra, where it connects with other railways leading to Lisbon and to Madrid. It is described as a remarkable undertaking, worthy of imitation by all railway companies in Spain, where it has rarely been understood that the interests of the companies and of the districts traversed by their railways should always be considered to be, and are, in fact, identical.

The railway is one of the most costly yet constructed in the country, for the average expenditure over the whole length of 112 miles has been at the rate of £17,600 per mile. The heavy cuttings were almost exclusively in rock; there are 3½ miles of tunnel, many viaducts, and the ironwork of the bridges alone cost £80,000. But, nevertheless, the company at once reduced the tariff to one-half of that which was permitted by the terms of the concession, which is also one-half of the ordinary tariff now charged on other Spanish railways. The Estremadura farmers had frequently no sale for their superabundant corn, and this railway not only allows them to export it to the coast and to the Levant, but the company has built large warehouses at Huelva where they are permitted to store it, receiving warrants from the company upon which the farmers obtain advances; and, moreover, the railway company has put on a line of steamers to the Levant, and undertakes, for half the price previously charged, to convey all agricultural produce from the hands of the Estremadura farmers to those of the Levantine purchaser. This is regarded as quite a revolution in the mode of treatment that Spanish producers had hitherto received from the railway companies, and as a system which inculcates a most useful lesson. The railway company undertakes in the same way to foster all other local industries.

O. C. D. R.

The Kaiping-Tientsin Railway in China. By ADOLF SCHWARZ.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereins, 1889, p. 239.)

The first, and at present the only railway in China, is the property of an English Company; it was commenced in 1880 at Kaiping, and constructed for a length of 7 miles in order to reach the local coal-pits; seven years later it was extended to Lutai, and in 1888 through Tongku to Tientsin, the whole length of the line being about 95 miles.

The rails are of the Vignoles type, weighing 64 lbs. per yard, and are fished and fastened to the sleepers in the usual way. The line is single throughout, and the gauge is 4 feet 8½ inches. The engines have two coupled wheels and a four-wheeled truck or bogie, and were made in England.

The mixed trains are thus made up: Next the engine is a long second-class carriage divided by a longitudinal partition into two compartments, with seats along the partition and sides of the carriage, and is for the use of the Chinese trades-people; following this is an open truck, with seats all round for work-people, goods, provisions, &c.; then very comfortable and even luxurious first-class carriages furnished on the American plan, and finally goods carriages, &c. The engine-drivers are English, the other servants natives.

After Tongku the following are the most important stations, viz.: Lutai, Tongfong, Suko Chinang, with goods-sheds, repairing-shops, &c., and Tongshan the terminus near Kaiping.

The average speed is about 19 miles an hour, and at present this will not be exceeded, but when the line is thoroughly established this will be increased to 30 miles or more.

The fare is very moderate, a first-class ticket for the whole distance costing only 5*s.* 2*d.*; the line is much used, and is very popular with the Chinese, and there is considerable traffic in coals, bricks, pottery, &c., and the line pays well. At first the Company had to contend against great difficulties and prejudices, but the people now are beginning to appreciate the great advantages of this means of travelling, and it is expected that when the line is extended 70 miles further to Pekin no further difficulties will be met with.

W. H. E.

Projected International Railway through the Centre of the Pyrenean Range. By J. M. DALMAN.

(Anales de la Construccion y de la Industria, Madrid, 1888, pp. 337 *et seq.*)

The only existing railway communication between France and Spain is at the two extremities of the Pyrenees, connecting Bayonne with Irun at the western, and Perpignan with Gerona at the eastern, end of the range. The intervening distance is about 280 miles, in which the extreme elevation of the mountain passes and other obstacles to railway construction are so great, that hitherto it has been impossible to raise the requisite amount of capital for that purpose.

An intermediate line has been often advocated, known as the Canfranc route, which would connect Saragossa with Pau, on the Toulouse and Bayonne Railway. This line runs northwards from Saragossa through Huesca, the capital of Upper Arragon, Ayerbe, and Jaca, and crosses the summit at the Pass of Somport, which is within a short distance of the much-frequented baths of Panticosa. Huesca being already connected by a railway 46 miles in length with Saragossa, there would remain about 140 miles to be constructed, 90 on the Spanish and 50 on the French side of the frontier. The project has received the sanction and support of the Spanish Government, and its realization would be assisted by a large subvention; but the Author contends that, in addition to its great cost, it is otherwise inexpedient to give it the preference, for the line has been laid out with maximum gradients on both sides of the frontier of 1 in 28, and with minimum curve radii of 166 yards, besides requiring a tunnel through the summit, which on the Spanish side is 4,350 feet, and on the French side only 3,616 feet above the sea-level, with a descending gradient of 1 in 30 throughout its whole length of 7,333 yards; while for nine months in the year the entrance to this tunnel would be liable to obstructions from the snow. Owing to the poverty of the districts traversed by it, this railway would have a very meagre local traffic.

Several other routes have been proposed further to the east, among which there are two alternative lines which start from Lerida, midway between Saragossa and Barcelona. The first of these, known as the Central Pyrenean line, follows the banks of the River Noguera Rivagorzana, and, crossing the summit at a height of 5,333 feet, near Puente del Rey, was intended to join the Toulouse-Tarbes Railway at Chaume. Concessions were granted, both by the Spanish and French Governments, and a pretence was made by a company of commencing the works; but after more than one extension of time had been granted and allowed by the company to expire, no progress having been made, the concessions were annulled.

The other project, which starts from Lerida, and would also terminate at Chaume or Saint Girons, is known as the Pallaresa line, owing to its following the course of the river of that name, *viâ* Tremp and Esterri. The studies have not been yet completed, but they already show that this route is beset by innumerable obstacles. The summit is no less than 6,166 feet above sea-level, gradients of 1 in 28, and curves of 166 yards radius, have had to be introduced, and there would be many cuttings in clay of a dangerously unstable and unsafe description.

The Author describes several other projects only to reject them as impracticable, and gives the decided preference to a line which, starting from the city of Monzon, 35 miles west of Lerida, would pass by Fonz, Barbastro, and the baths of Estadilla, all in the valley of the River Cinca, and then take a north-easterly direction along the course of the River Essera, through such important towns as Graus and Campo. It would traverse an extensive coal-field at Castejon de Sos, and reach the French frontier at Venasque, which is only 63 miles distant from Monzon, and 7½ miles from Bagnères de Luchon, with railway communication thence to the rest of France.

The summit would be pierced at Venasque by a tunnel which, on the Spanish side, would be 4,083 feet, and, on the French side, 3,817 feet above the sea; the maximum gradient on the line is 1 in 40, and the minimum curve-radius 333 yards, on a very limited number of curves. The route is described as one which would provide abundant local traffic, the lower part of the valleys being rich in agricultural, and the upper part in mineral and metalliferous, produce. Estimates of the local and general traffic are given, and it is stated that, besides being already in direct railway communication eastwards with Barcelona, and other important Catalonian towns, and in the opposite direction with Saragossa, Madrid, &c., a railway is proposed from Monzon southwards to the excellent port of Los Alfaques, at the mouth of the River Ebro, in which event this railway from Bagnères de Luchon through the Pass of Venasque to Monzon would become the shortest route, not alone from Paris to Saragossa and Madrid, but also from Paris to Valencia and to the French colony of Oran, as is apparent from the tables which accompany the Author's interesting and comprehensive Paper.

O. C. D. R.

Consumption of Railway Sleepers in France. By H. MATHIEU.

(Revue générale des Chemins de fer, July 1889, p. 3.)

Referring to a previous article on the consumption of transverse wood sleepers on railways in France,[1] in which the Author investigated the returns for the years 1878 to, and inclusive of,

---

[1] Minutes of Proceedings Inst. C.E., vol. xci. p. 485.

1886, he directs attention to the returns for the years 1887 and 1888.

The total length of single way for the six leading railways, with the State Railways of France, amounts to 92 per cent. of the total length of single way in France; and the general deductions for this proportion are taken as applicable to the entire railway system for purposes of calculation.

The final results of comparison are given in the subjoined Table:—

Year.	Number of Sleepers Consumed on all the Railways of France.	Total Length		Number of Sleepers Consumed per Mile of Single Way.
		Of Railways.	Of Single Way.	
	Sleepers.	Miles.	Miles.	Sleepers.
1887	2,405,538	21,114	29,256	82·2
1888	2,521,270	21,643	29,914	84·3

The consumption of sleepers for maintenance in previous years, down to 1888, has been as follows:—

	Sleepers per Mile per Year.
1878 to 1882	148·1
1883	170·7
1884	142·7
1885	111·9
1886	87·8
1887	82·2
1888	84·3

The remarkable and steady reduction of the number of sleepers annually for maintenance is attributable to the increased care taken by the companies, to the new methods adopted for the replacement of sleepers, to the creosoting of the sleepers of all kinds of wood, to better fastenings, to the selection of good ballast, and finally, to the augmented weight and strength of the rails.

The total numbers of sleepers consumed for maintenance and for construction of new lines, in France, were as follow:—

	Maintenance.	Construction.	Total.
1887	2,405,538	1,452,094	3,857,632
1888	2,521,270	1,280,030	3,801,300

The sleepers were, for the most part, of oak; next, in order of quantity, were sleepers of beech and of fir. Of these, about 93½ per cent. were supplied from the forests of France; the remainder were imported.

Metal transverse sleepers are still on their trial on the State Railways. There are 45,000 metal sleepers of all kinds.

D. K. C.

On the Duration of Steel Rails. By — Coüard.

(Revue générale des Chemins de fer, July 1889, p. 13.)

Referring to a previous communication,[1] Mr. Couard continues the investigation, with a view to determining the duration of steel rails. From a consideration of the results of German practice, published by the Verein, for the period 1879–84, he deduces the following law: The diminution of height of steel rails, after the passage of a certain number of trains, is proportional; (1) to the average tonnage of the trains; (2) to their average speed; (3) to the deflection of the rails between the supports; (4) to a coefficient varying with the place of manufacture; (5) to the inclines, greater on the descending than on the ascending inclines. This law is expressed by the formula—

$$N = \frac{10^6}{T\,V} \times \frac{I}{L^3} \times \frac{1}{1 + a\,D^2} \times C.$$

N = number of trains corresponding to a diminution of 1 millimetre of height of head of rails;
T = average weight of train, in tonnes;
V = average speed of trains in kilometres per hour;
I = moment of inertia of section, calculated in centimetres;
L = distance apart of sleepers, in metres;
D = inclination, in millimetres per metre;
a = coefficient, equal to $0 \cdot 023$ for descending inclines, and to $0 \cdot 012$ for ascending inclines;
C = coefficient for place of manufacture.

By comparison with the results of wear on the Paris and Lyons Railway, it appears that the French rails are twice as resistant to regular wear as the German rails. The difference is attributable entirely to the nature of the steel of which the rails consist; the German steel is the milder—the less carburetted steel deflecting more than the French steel—and wears faster under the rolling friction.

It appears that the wear of steel rails is ten times as much under sliding friction as under rolling friction.

It is shown that the passage of from 150,000 to 200,000 trains is required to wear down the head of the rails weighing 86 lbs. per yard, to the extent of 1 millimetre of height, the rails being carried on sleepers not more than 2·62 feet apart. To extend the regular wear to 15 millimetres (0·59 inch), under trains at the rate of 10,000 per year, would require a period of from one hundred and fifty to two hundred years. This calculation shows why the rails replaced because of regular wear are collected almost exclusively from tunnels, stations, and steep inclines.

---

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvi. p. 407.

Numerous tables of the results of investigations, with diagrams of wear of the rails from different causes, are given in the Paper.

In conclusion, it is argued that a steel rail will last longer the less the deflection between the sleepers, and that hard steel is preferable to mild steel. Heavy rails are recommended. For ballast, gravel or broken stone is preferable to sand.

D. K. C.

The New Rail of the Paris, Lyons, and Mediterranean Railway.

By J. Michel.

(Revue générale des Chemins de fer, June 1889, p. 372.)

This railway company, in 1868, when the use of steel as a material for rails was introduced, adopted a flange rail of steel, weighing 78·62 lbs. per yard, 5·12 inches wide, and 5·12 inches high; width of head, 2·36 inches, with flat vertical flanks. This profile has been substantially adhered to for twenty years, but six years ago the depth of the head of the rail was augmented by 1 centimetre (0·39 inch), as a provision against the special wear caused by brakes on inclines and near stations, and oxidation in long or insufficiently ventilated tunnels. The rail thus reinforced weighed 87·70 lbs. per yard. It was rolled to lengths of 39·36 feet (12 metres), in place of half this length, as theretofore. And, in view of the increase of weight on axles that had taken place in the course of twenty years, to the extent of 10 per cent., it appeared desirable to augment the width of the head by one-tenth, making a width of 2·60 inches. It was decided also to augment the thickness of the flange by 1 millimetre, to allow for the observed wear that took place in the course of years. The head of the rail, also, has been augmented 11 millimetres in thickness.

In this way the new rail was matured. The total height is 5·59 inches; the head is 2·60 inches wide; the base is, as before, 5·12 inches wide; and the rail weighs 94·75 lbs. per yard. The upper or rolling surface of the rail is as nearly as possible of the form of surface acquired by wear after several years of service. It is curvilineal, to a radius of about 12 inches. The sectional area of the rail is about 9·34 square inches, and the material is so distributed that the centre of gravity of the section is exactly at the middle of the height of the rail, thus equalizing the working of the material, and utilizing all the resistance of which the section is susceptible, in whatever direction flexure may take place.

The article is concluded by a table of various types of steel rails—French, Belgian, Dutch, English, and American. It is shown that the width of the head varies from 2·56 inches in

America, to 2·83 inches in Belgium. The augmentation of width here shown affords space for increased bearing of fish-plates.

The augmentation of width of head involves a corresponding contraction of gauge, or clear width, between the rails; and, in effect, the gauge of the way will be 56·850 inches instead of 57·086 inches.

D. K. C.

The Use of Flangeless Wheels in the Middle of Six-Wheel Trucks.

(National Car and Locomotive Builder, Chicago, 1889, p. 115.)

Mr. W. A. Scott, late assistant-superintendent of motive power of the Chicago and North-Western Railway, has experimented on flangeless wheels for the six-wheel trucks used under passenger-cars with encouraging results, the probable outcome being a six-wheel truck that will effect a great saving of tires, while materially reducing the resistance offered by the present truck. The investigations have resulted in a design of axle-box in combination with one set of wheels with flangeless tires, which has been patented. Trucks with a special box and flangeless wheels have been running on the Chicago and North Western, and Chicago, St. Paul, Minneapolis, and Omaha Railroads for several years with great saving to the companies.

The economy of this truck is considerable, as where steel tires are used at a cost of $30 to $40 per tire, the entire cost on six-wheel trucks is reduced by one-third. When the leading wheels of a truck become flange-worn to an extent that would make it essential to scrape them, all that is now necessary is to take that pair of wheels and turn the flange entirely off; this leaves the tread from 1 inch to 1⅝ inch thick, and enables the same tire to be used flangeless in the centre of the truck for a mileage that will exceed that which was formerly obtained with the flanges on. Tires are being constantly turned down in order to get good flanges; frequently three-eighths of the tread are removed for no other purpose than to furnish a suitable flange. Often with a tread 1⅝ inch thick, the tire must be turned down ⅝ inch to get a suitable flange and fillet, thus rendering the tire useless, as 1 inch thickness of tread is the minimum for safety with most roads. In such case the Scott truck allows of such a tire being turned off smooth to probably 1½ inch thick and flangeless. Such a pair of wheels can be put into the middle of the truck, where it will wear for 400,000 or 500,000 miles, thus saving that much mileage to the company, for the tire would under flange conditions be useless.

A car with flangeless centre wheels requires less motive power to haul it, as on curves it does not in any sense bind. This has been illustrated by placing a coach with two six-wheel trucks, all wheels flanged, on a certain curve, when it took thirty-two men to push the truck 150 feet. A coach of the same class and weight with six-wheel trucks, with flangeless wheels in the centre, was next selected, when nineteen men pushed it the same distance over the same track as easily as the thirty-two men did the other coach. Again, in times of snow, there are on each car four flanges less to be clogged inside the rail, making the hauling of the car 30 per cent. easier. Finally, the wear on the side of the rail is largely reduced, especially on curves, by the use of this truck, as there is one-third less flange-bearing to each car; which, of course, wears the rail in the swaying of the train much less than if all the wheels had flanges.

F. G. D.

Experiments with the New Quick-Acting Westinghouse Brake on the Baden State Railway. By — Emmerich.

(Verhandlungen des Vereins für Eisenbahnkunde in Berlin, 1889, p. 60, 2 woodcuts.)

The Author first notes the fact that in 1886 tests were made in the United States of continuous brakes for goods trains, which were hardly satisfactory, and also that in 1887 comparative tests were carried out there upon the Carpenter, Card, Westinghouse, and Eames brakes, of which the first two were operated by electricity alone, while the other two used an electric current only as an auxiliary to the ordinary method of working. The report of the Committee who carried out these tests was to the effect that the best brake for long goods trains was one worked by air-pressure or vacuum, and in which an electric current was used to actuate the valves. The Author then proceeds to describe the new quick-acting Westinghouse brake, and to give the following account of comparative tests made with it, and with the older form of the same brake, upon a straight horizontal piece of line near Philippsheim, on the Baden State Railway; the starting point was marked by a flag, while there, and at distances of 200 and 400 yards before this point, a fog-signal was placed upon the rail for the purpose of noting the speed of the train. Time, distance travelled, air-pressure, and speed were all measured in the last wagon, which was connected by telephone to the locomotive, and the arrangements were specially made for the purpose by Mr. Kapteyn.

The trains used for the experiments were made up entirely of wagons fitted with air-brakes, and were five in number. (1) Three trains of eighteen wagons, each fitted with (*a*) the ordinary Westinghouse brake and pipes of 1 inch diameter; (*b*) the quick-acting Westinghouse brake and pipes of 1 inch diameter; (*c*) the quick-acting Westinghouse brake and pipes of 1¼ inch diameter. (2) A train of thirty wagons, fitted with the quick-acting Westinghouse brake and pipes of 1¼ inch diameter. (3) A train of fifty wagons, fitted with the quick-acting Westinghouse brake and pipes of 1¼ inch diameter. The trains of eighteen wagons were about 182 yards long, that of thirty wagons was about 294 yards, and that of fifty wagons about 524 yards long. At a speed of 43·4 miles per hour, and air-pressure of 52·5 lbs. in the cylinder of the last wagon, the distance travelled after application of the brake was for trains No 1. (*a*) 223 yards, (*b*) 201 yards, (*c*) 216 yards; the action of the brake began in the last wagon after $\frac{7}{8}$, $\frac{1}{4}$, $\frac{5}{8}$ second; the duration of braking was $17\frac{2}{8}$, 17, $18\frac{1}{2}$ seconds, and reached its full effect after $3\frac{1}{4}$, $1\frac{1}{4}$, and $1\frac{1}{8}$ seconds respectively. No. 2 train similarly gave for distance 228 yards, and No. 3 gave 230 yards. The Author draws particular attention to the small difference made by the length of the train, eighteen wagons being pulled up in 216 yards, and fifty wagons in 230 yards, and draws the conclusion that electricity is not necessary for obtaining a uniform braking-force, as by this new arrangement the action is sufficiently speedy with less complication. He then proceeds to discuss the reasons for and against the equipment of goods trains with continuous brakes, and notes the fact that in braking the train of thirty wagons the shock was barely perceptible, while in that of fifty wagons couplings were twice broken. E. R. D.

Koyl's Parabolic Semaphore.

(Journal of the Franklin Institute, August 1889, p. 81.)

The Committee on Science and the Arts, of the Franklin Institute, have reported on the system of railroad signalling devised by Professor C. Herschel Koyl. The arm of the semaphore is not flat, as usually constructed, but is approximately parabolic in plan, and is partly covered with glass, slightly corrugated, in order to scatter the light reflected from its surface. The arm itself is from 7 inches to 11 inches in width, and is painted bright red, with the exception of the medial band of corrugated silver glass, which is 4 inches wide. It can be seen during the day in a horizontal position as clearly as the ordinary flat semaphore arm. But the parabolic surface is illuminated at night by a lamp placed at the focus of the paraboloid. The lamp is protected on the plane of the horizontal arm by red glass, and shows a strong red band upon the line of the way, and for a considerable distance on each side of the way, so as to be visible to the man on the engine when approaching the signal on a curve of the road. The lower part of the lantern used to illuminate is made of clear glass; and the arm, when dropped to, say, an angle of 45°, passes from the red rays of the transmitted light, and is made to reflect the direct light of the lamp, so presenting a strong contrast to the red signal of danger visible when the arm is in a horizontal position. When, during the day, the arm has fallen to the position of safety, the glare from the strip of glass, lighted by the sky only, causes the signal to be more striking than the arm in common use.

The parabolic semaphore is found to be specially useful in the neighbourhood of cities, where lights are numerous; in wooded or hilly countries, with dark back-grounds; and near curves. During winter, dry snow never lodges on the blade; wet snow and frozen snow are found to be themselves excellent reflectors.

The communication is illustrated by photo-lithographs.

D. K. C.

The Tramways of Madrid.

(Anales de la Construccion y de la Industria,' Madrid, 1888, p. 62.)

Notwithstanding the very uneven ground on which it is built, Madrid is traversed by tramways from one extremity to the other, with branches to most of the suburbs. The first line was constructed in 1871, from the fine suburb of Salamanca, which skirts the fashionable Prado, through the chief streets of the city, the Calle de Alcalá, and the central square, called the Puerta del Sol, to beyond the Royal Palace at the other extremity. The several routes are altogether 24 miles in extent, and for two-thirds of this distance the line is a double one. Terminal stations, coach-houses, stables, and repairing shops have been built on a handsome scale, and the stock consists of two hundred and twenty comfortable cars, and one thousand three hundred and ninety-six mules and horses. Upwards of one thousand men are employed in the service of the companies.

O. C. D. R.

Shallow-Draught Screw-Steamer.

(Industrie Moderne, 1889, p. 171, one woodcut.)

The article describes a screw-steamer of small draught of water, built by Mr. Oriolle, of Nantes. The vessel is intended for river service. She is 65 feet in length, 11 feet 3 inches in beam, 2 feet 1½ inch in depth, and draws barely 10 inches of water. She is propelled by means of a four-bladed screw, 2 feet 9½ inches in diameter, and 3 feet 11 inches pitch. This screw is placed in a tunnel hollowed out in the bottom of the vessel, the crown of which rises considerably above the water-level in order to give room for the propeller, which does not project below the bottom of the boat. The forward and after-ends of the tunnel dip down below the water-level, and when the air is exhausted by means of a pump, the screw is completely immersed.

The speed attained on the measured mile was 8·15 knots per hour, with a boiler-pressure of 70 lbs. per square inch and 300 revolutions per minute. The engine developed 40 indicated HP. It is stated that, with a boiler-pressure of 130 to 140 lbs. per square inch, and with 450 to 500 revolutions per minute, it would be possible to obtain a speed of 10 to 11 knots.

S. W. B.

"Turret Barbette" on the Canet System for 12·6*-Inch Guns.*

(Le Génie Civil, vol. xv. 1889, p. 316, 1 illustration.)

The article describes the system of gun-mounting devised by Mr. G. A. Canet, Assoc. M. Inst. C.E., which is a combination of turret and barbette.

It has been adopted as the mounting for the 12·6-inch guns in three coast-defence vessels building for the Japanese Government. The guns and mountings are made by the Société des Forges et Chantiers.

The Canet steel gun has a length equal to 40 calibres, and weighs 66 tons. It has no trunnions, but is strapped down to the slide by hoops passing round it. The weight of the projectile is 992 lbs., and of the charge 617 lbs. The muzzle velocity is 2,300 feet per second, and the shot will penetrate, at the muzzle, an iron plate 3¼ feet thick, or a steel plate of 2¼ feet. The maximum range is 12½ miles, with an elevation of 30°. It is said to be the most powerful gun of its size in existence.

The gun fires over a fixed barbette, protected by 12-inch steel armour-plate. Within the barbette is a central tube for the passage of the ammunition, extending downwards from the base of the barbette to the armoured deck below. This tube is about 10 inches thick. The internal diameter of the barbette is 23 feet 6 inches. The gun-slide is mounted upon a turn-table, which carries also hydraulic apparatus for elevating and depressing the gun. Attached to the base of the turn-table, and working within the armoured tube before mentioned, is an inner tube or trunk, the lower end of which opens into the magazine, which is immediately below the barbette.

The ammunition hoists are inside this inner tube, and turn with it. The rack for revolving the turn-table and gun is placed round the lower end of this inner tube, which protrudes below the armoured deck, and the hydraulic turning-engine gears directly on to it.

The charge is in two parts, which, together with the projectile, are transported in carriages to the mouth of the shaft. They are there placed in a carrier, which revolves, as before explained, with the gun. The carrier ascends the tube on guides, and, on reaching the barbette, these guides are bent out in such a way as to transport the carrier with the charge immediately under the breech of the gun. When the breech is opened, the carrier is raised into line with the gun, and it can then be revolved by hand, so that the projectile and the two halves of the charge are presented in turn to the gun, into which they are thrust by a hydraulic rammer, which is above the top of the parapet. The stroke of the rammer is so adjusted, after each operation, that the projectile and the two cases of powder are just pushed into their proper place, and injurious compression of the powder is thereby avoided.

Above the top of the parapet, and attached to the turn-table, is what is called a turret. It is composed of plates about 5 inches thick, and protects the breech of the gun, the loading apparatus, and the man directing the gun. The base of this turret at the rear projects about 3 feet beyond the edge of the parapet, in order to cover the hydraulic rammer. The "turret" revolves with the gun, which fights through a port in it.

All the movements are performed by hydraulic apparatus, working at a water-pressure of 1,200 lbs. per square inch.

S. W. B.

An Exposition of the Mode in which Water is Affected by a Body Moving in it.

By Chief Engineer B. F. Isherwood, U.S. Navy.

(Journal of the American Society of Naval Engineers, vol. i. p. 97.)

In his account of the "Progressive Trials of the Steam Barge of the Commandant of the New York Navy Yard," the Author gave an explanation, from observations made by himself, of the phenomenon of "squatting," or the change of trim which a vessel experiences when its speed surpasses a certain limit (variable for each vessel). In the discussion which ensued upon that Paper several objections were urged to the Author's theory by Past Assistant-engineer Mattice. In the present article the Author enlarges upon his former theory, and replies to these objections. He demurs from Mr. Mattice's statement "that a vessel might be made with an after-body of sufficient length and of proper form to allow the cavity at the stern, caused by the forward motion of the vessel, to be filled with sufficient rapidity by the inflowing water; but that 'squatting' might still result from the hollow of the bow or displacement wave occurring somewhere along the after-part of the vessel, and that, when the hollow of the bow wave coincided with the hollow caused by a full after-body, the 'squatting' would be a maximum." He attributes "squatting" solely to the incomplete filling of the cavity at the stern, from the speed of the vessel being too great to allow the water to flow in with sufficient rapidity. Comparing the bow or displacement waves with the waves caused by paddle-wheels, he concludes that the bow-waves are too shallow to account for "squatting"; and besides that the depression at the stern is between the extended sides and the immediate wake of the vessel, while the hollows of the bow-undulations are exterior to the extended sides. So far from Mr. Mattice's deductions as to the influence of length of vessel upon "squatting" being true, the length of the vessel appears to be, if not the only factor, certainly the principal one in determining the speed at which "squatting" commences.

The Author denies the existence of a following wave, and maintains that the water rises vertically from the horizontal plane of the rabbet of the keel into the cavity at the stern, and does not flow in horizontally or from the sides. The *vis viva* of the ascending column of water carries it above the surface, and it then flows out in all directions over the surrounding plane. It is only where there is an insufficiency of water beneath the keel of the vessel that any water flows in horizontally or from the sides. There is thus a purely surface-current in all directions from the capital of the ascending column, and that portion of this surface-current which flows towards the vessel it is which is erroneously called a following wave, and which accounts for such phenomena as the towing of a small boat with a slack tow-rope behind a vessel going slowly, &c. The Author draws illustrations and confirmation from the effects produced by paddles upon the water, and also from the screws of vessels secured to the dock while their engines are working. He digresses to show the reason for the increase in the efficiency of paddles in a head wind or sea, and the corresponding decrease in the efficiency of the screw. One great cause is the change of angle of inclination which takes place in a screw-shaft, and the consequent alteration in the angle of thrust, while with paddle-wheels the thrust always remains horizontal. This effect is increased by "squatting."

Returning to the direction of influx of the water at the stern, the Author discusses its bearing upon the correct formation for the after-body of a vessel. He gives the results of his observations of the flow of water past the piers of a bridge over a quickly-flowing stream; and from these he argues the impossibility of a negative slip, and concludes by regretting that the information should be so doubtful and incomplete regarding the only instances of negative slip of which he is aware, namely, those which are given in the Admiralty reports of the speed and power trials of British war-vessels.

D. S. C.

Experiments on the Removal of Mine Gas by Exhaustion.

By H. Brenner.

(Zeitschrift für das Berg- Hütten- und Salinenwesen, 1889, p. 70.)

At the King's mine at Grevenberg, near Aachen, a series of experiments was carried on between the years 1866 and 1888 by the late manager, Mr. D. Hilt, having for their object the direct removal of the gas given off by the coal by means of an exhauster. The seam on which the trial was made varies from 6 to 6½ feet in thickness with a dip to the south varying from 20° to 50°. The coal is got in pillar work, the pillars 50 feet high (measured to the rise) being separated by levels of 16½ feet, which are further divided by a middle wall made of stone partings and small coal into two roads of 6½ feet each, an arrangement that allows the air to be carried well into the front of the heading.

The ventilation of the mine is considered to be very good, from 100 to 140 cubic feet per minute of fresh air being provided for each of the fifty-five to sixty men working in the district under consideration.

The removal of the gas was effected by a disused compresser which, by an alteration of the valves, was made to do duty as an exhauster. The cylinder was 471 millimetres in diameter, with a stroke of 936 millimetres, giving a capacity 0·16 cubic metre per stroke, which, at 15 revolutions per minute, corresponded to 6,912 cubic metres (244,000 cubic feet) per twenty-four hours. From the engine a main pipe of 3¾ inches diameter was carried down the pit and for a distance of about 1,300 yards, when secondary pipes of 2 inches were placed for about 300 yards in the main levels. Finally smaller pipes, of 1-inch bore and terminated by plate suction-roses, were extended into the front of the headings, and kept to the top of the level by clamps attached to the timbering. The roses were at first made of tin-plate perforated with fine holes on both sides, but these were found to admit too much air on the under side, especially in a weak gas current, so that ultimately the under side was closed and the perforations on the top surface were correspondingly enlarged. In places where the dip of the seam was comparatively low, the roses were made of a long rectangular form and covered with wire gauze like that used in safety-lamps. Vacuum-gauges were inserted at different points in the tubes to measure the effective rate of exhaustion. This, during the period of the principal experiments in February to May, 1887, varied from 235 millimetres water column near the pit bottom to 40 millimetres at the end of the main pipe of 1,330 yards and 30 millimetres at the end of the secondary main. In the inch pipe it varied from 25 millimetres to 2 millimetres at the most distant suction-rose, which was about 325 yards away. For a short time a Körting steam-jet exhauster was tried, but it did not prove equal to the work, the depression at the measuring station No. 2 being only 10 millimetres, instead of 40 millimetres realized by the pump. The flow of the exhausted gases was regulated by a double-bell gasholder, so arranged that while one bell was being filled the other was delivering. This, however, did not work satisfactorily and was abandoned, the gases being forced directly by the pump into the delivery-pipe. Several small gasometers were used for collecting gas for experimental purposes and testing, the latter being done every twelve hours.

The experiments as a whole proved a decided failure, on account of the fluctuation in the composition of the gas, which sometimes contained as much as 10 per cent. of firedamp and sometimes none, the variations taking place without any apparent cause.

The continued attention required in extending and varying the position and area of the suction passages was also very considerable, and such as to cause considerable hindrance in the levels when the driving was actively carried on.

The gas was applied to the firing of two boilers, a row of jets being introduced below the firebars from a tube which was connected with the main by a safety U tube sealed with water, and at all the joints of the pipes wire-gauze diaphragms similar to those used in safety-lamps were inserted.

The boilers were experimented on for some time, but neither a more active evaporation nor any saving in fuel was obtained. The gas was also tried with the magnesia comb burner of Fahnjehelm, but only the lower third of the bars could be brought to the proper degree of incandescence. The third suggested application of the gas, namely, for driving gas-engines, was not tried.

H. B.

Report upon the Coal Deposits in the Indwe Basin and Stormberg Range of Mountains. (51 pp and 5 plates.[1])

By W. GALLOWAY, Mining Engineer.

This is a report drawn up for the Commissioner of Crown Lands and Public Works, Cape of Good Hope, for the purpose of deciding: (*a*) The extent of the coal deposit; (*b*) the quality of the coal with reference to first-class English coal; (*c*) the best means of working the coal, and an estimate of the value of the property. Further, in framing the estimate, consideration to be given to: (*a*) the distance of the mines from any existing railway; (*b*) the limited demand for coal; (*c*) the competition of other mines; (*d*) the competition of English coal; (*e*) the value of the fuel for marine purposes.

Geographically, the South African Coal-field embraces parts of Cape Colony, Orange Free State, Transvaal, Natal, and the whole of Basutoland, the greatest length and breadth being 500 and 200 miles respectively, and enclosing an area of 56,000 square miles, in which coal has only been worked in the extreme edges at far distances apart in the Stormbergen Range near Molteno, at Indwe in Natal, and in the Transvaal.

STRATIGRAPHICAL RELATIONS of the COAL-BEARING ZONE.

		Approximate thickness in feet.
Volcanic rocks.		
Cave sandstone.	Buff grey sandstone	300
Red beds	Red and purple sandstones and shales.	1,500
Coal-measures.	Coarse grey quartzose grits and conglomerates; a few thin shales and clay stone	1,000
Karroo	Fine grained, soft white, buff red, purple and mottled beds of sandstones and shales, with a slight tendency to spheroidal weathering	5,000

---

[1] The original is in the Library of the Inst. C.E.

The whole of the ground is seamed through with dolorite in the form of dykes and horizontal sheets. The districts examined were:—

I. Gubenxa Tsomo. Five seams described, from 18 inches to 27 inches thick.

II. Indwe. Here occurs the most important seam, the Indwe seam, the only seam workable, in a plain formed by the Guba and Doorn Rivers, where they fall into the Indwe. The dip of the seam is from 1° to 2° from south to north. Dykes of dolorite traverse the seam in every direction. At seventeen various points, where the Indwe seam has been exposed and worked, the coal varies from 5 feet 7 inches to 1 foot 8 inches in thickness, with a specific gravity of 1·43 to 1·61. The Author gives detailed sections of the seam, from which it appears that numerous thin coal and shale bands are intimately intermixed. At the Indwe mine, the most important mine, the height of the workings is 6 feet 10 inches with 3 feet 8 inches of good coal and 8½ inches of inferior coal. The area worked is 4 acres, producing nearly 5,080 tons of coal per acre. The system of working is a kind of long wall. The roof is sandstone. The seam is undercut in shale near the roof, and the bottom and top coal blasted by Kafir colliers. A little water is made. Quantity of coal in the Indwe field: the Author assumes an average thickness of 3 feet 8 inches, and a specific gravity of 1·4, an available quantity of 4,000 colonial tons per acre, which, over an area of 118 square miles, gives 302,000,000 tons of coal.

ANALYSES by DR. HAHN.

——	Thickness.	Specific Gravity.	Volatile Constituents.	Coke.	Ash.
	Inches.		Per cent.	Per cent.	Per cent.
Top seam . . .	11	1·26	19·57	80·43	11·08
Middle ,, . . .	25	1·48	15·32	86·68	28·87
Bottom ,, . . .	11	1·46	17·13	82·87	24·65

Ultimate analysis by Dr. Hahn, carbon, 61·021; hydrogen, 3·208; nitrogen, 2·190; sulphur, 0·434; oxygen, 2·178; ash, 30·32; coke, 75·26. Normally, the coal contains 30 per cent. of volatile constituents, 20 to 30 per cent. of ash, and has a specific gravity of 1·4 to 1·5. The drawback of Indwe coal as a fuel is the large amount of ash, necessitating grates of large area, and mechanically moving firebars. Calorifically compared, 1 ton of Welsh coal is equal to 1½ ton of Indwe coal.

Table B gives an estimate of the annual saving of using Indwe coal over Welsh coal on most of the colonial railways, when the latter costs, per ton of 2,000 lbs. at Cape Town, £1 16*s*. 4*d*.; Port Elizabeth, £2 4*s*. 4*d*.; East Linden, £2 11*s*. 5*d*.; and the former, at the mine, 5*s*., and at Imwani, 12*s*. 2*d*. per ton. If ⅝*d*. per ton per mile represents the actual cost of railway carriage of Indwe coal, then this coal cannot compete with Welsh coal at Cape Town; to do this, the carriage would have to be reduced to ½*d.* per ton per mile. Average water evaporated per lb. of coal was found to be 5·62 lbs. in a locomotive. The Author gives his reasons for the fuel being unsuitable for marine purposes, and he estimates the cost of working at 5*s.* per ton in workings over 1,000 yards beyond the outcrop. It is unlikely that firedamp will be met with. The seam can be worked by adits from the outcrop, and drained by a water-surface rising 1 in 500 from the hillside, or shafts can be sunk 500 to 600 feet deep. The Author then goes on to deal with the estimated cost of working the coal, proposed methods of opening out and working the seams, ventilation—by means of underground fans worked by electricity—haulage—by steam and later by electricity, the electricity to be generated by means of triple-expansion engines, with steam from steel Lancashire boilers at 160 lbs. pressure—screening, breaking, and handpicking the coals, and an elaborate scheme for dealing with native labour assisted by European labour, and special laws to be made by the Government. The cost of establishing a colliery, with machinery requisite for raising 300 to 400 tons per day, is given in Appendix I, Appendix II containing results of trials of colonial coal on the eastern system of railways.

III. Stormberg seam, a seam thinner and inferior to the Indwe seam, and which occupies the same geological horizon.

The Author here deals with the question of the formation of South African coal-beds, which he supposes to be of subaqueous lacustrine origin. The prevailing dip of the Stormberg seams is 3° in the direction 45° E. of N. The present number of mines is six; they are small, raising from 15 to 20 tons of coal per day. The coal varies from 2 feet 2½ inches to 2 feet 7½ inches in thickness with a shale roof.

Quantity of coal: the Author assumes an average thickness of 1 foot 10 inches, a specific gravity of 1·4, available quantity, 3,000 tons per acre, then 10 square miles gives 19,000,000 tons of coal. One ton of Welsh coal = 1·71 of Stromberg coal, and contains ash from 37·6 to 44·2 per cent. The Author assumes the cost of selling this coal at the pit's mouth to be 10*s.* per ton.

C. Z. B.

Maliwun Tin Mines (Mergui District).

(Indian Engineering, July 20, 1889, 1 plate.)

The Author describes a visit to the almost deserted tin mines of Mergui, near Renaung, the well-known capital of one of the most flourishing tea districts of Siam. The veins of tin-sand are met with at the surface; the sand is mined in open workings by shallow pits from 10 to 12 feet deep. Water-power is used to drain the mines in a very primitive manner. Europeans are not allowed to descend the mines without some trouble. The sand is raised by ladders from the mines and washed, a cubic foot of quartz and sand yielding, after washing, half a teaspoonful of tin-sand. The miners are paid either by the month or by the amount of sand collected, their wages ranging from Rs. 10 to Rs. 15 to Rs. 25 per month. Rs. 7 per "khan" (a small basket equal to $\frac{1}{16}$th of a bushel) are paid for sand collected. The two smelting furnaces are situated at Maliwun—a drawing of a furnace used is attached. The furnace is of an ingenious contrivance, and has an air-pump attached for blowing. The wages of the smelter varies from R. 1 to Rs. 1–4 a day. The output per day is fifteen to sixteen blocks of tin of 106 lbs. each, fetching about Rs. 60 at Penang.

The Author compares this mining district, which is in a deplorable state, with the flourishing condition of the Renaung mines, worked by the Raja of Renaung with Chinese labour. The Raja has studied the wants and manners of the Chinese labourers; he allows them gambling-houses, and opium is publicly sold.

C. Z. B.

Report on the Oil-Fields of Twingoung and Beme, Burma.

By Fritz Noetlong, Ph.D.

(Records of the Geological Survey of India, 1889, p. 75.)

These oil-fields, worked from wells sunk by the natives of the district, are situated about 1½ mile from the Irawaddy, in 29° 21′ N. latitude and 94° 56′ E. longitude. From a map of the district, affixed to the report, it appears that the Twingoung wells, spread over an area of 90 acres, are about ¾ mile distant from those of Beme, which cover 35 acres.

While oil has been produced from the Beme district for one hundred years back, and from Twingoung for seventy years, that region lying between these two districts has been, to the surprise of the Author, left intact; and it is in this region that Messrs. Finlay Fleming and Co., who have obtained a lease of the district, have commenced operations. The country is formed by a level plateau, having an average height of 260 feet above the low level of the Irawaddy, intersected by irregular ravines, running towards the river, with steep notched slopes, rendering cross-roads, in most localities, impossible. The geological formation of the district is believed to be that of the Upper Tertiary, of a not later age than the Miocene. A plate is furnished giving nineteen sections of the strata at Twingoung to varying depths, up to 400 feet; and from this, and other information given in the report, it may be gathered that, to a depth of 200 feet, there exist sandstones mixed with clay; at 200 feet there is a change to grey clunch, which continues for 20 feet, after which there are beds of sandstone containing oil until a depth of 270 feet is reached; at 300 feet is found a bed of soft sandstone, 65 feet thick, unequally charged with oil; and below 365 feet is a conglomeratic sandstone, of light green colour, impregnated with oil.

The upper group of these beds, reached at a depth of 220 feet, though containing a considerable quantity of oil, cannot be considered as the oil-bearing formation proper, as wells sunk to its depth never yield large quantities of oil. The lower group, reached at a depth of 300 feet, and, so far as is known, of a total thickness of 180 feet, is saturated with oil. It is, however, divided up by layers, estimated at 50 feet thick, of clay and hard sandstones, leaving only 130 feet of really known oil-bearing sandstone. The strata form an anticline whose axis passes through the fields of Twingoung and Beme. Being therefore situated on the summit of the anticline, the oil is reached in their neighbourhood, at the minimum depth, the strata dipping on each side at a maximum angle of 35°. It is estimated that, at ½ a mile on each side of the axis, a well of 3,000 feet depth would be necessary to drain the oil-bearing strata; and as this depth is as great as is likely to be practicable, a total width of 1 mile is given as that of the oil-field. Although, as a rule, at the greater depths more abundant supplies of oil are obtained, this does not invariably apply, as it has been found that wells sunk to the same level yield widely varying quantities. This somewhat perplexing occurrence has been explained by the existence of bands of clay which run through the strata, cutting off and partially isolating certain portions, so preventing their complete saturation with oil, or, on the other hand, forming reservoirs of other portions which retain the oil. Under these circumstances, no opinion can be formed as to the depth at which the richest beds are to be found; though a general opinion is given that not less than 400 feet from the centre of the anticline is necessary to obtain good results.

The physical and chemical constitution of the oil has not been examined by the Author.

At Twingoung there have been sunk by the natives 375 wells in all, of which 166 are now unproductive and disused, 89 give intermittent and scanty supplies, leaving 120 only in full work. At Beme the number of wells is 151, of which 57 are disused, 22 partially productive, and 72 in full work. The greatest depth reached by the wells is 310 feet at Twingoung, and 270 feet at Beme. Of 236 wells actually measured, 3 only are more than 300 feet deep; 30 are from 250 to 300 feet deep; 111 are from 200 to 250 feet deep, and 92 are up to 200 feet deep. None of these have much more than reached the oil-bearing strata proper, while the conglomerate sandstone, richest in oil, known to be 100 feet thick, is untouched by them.

Great difficulty has been experienced in obtaining data regarding the past production of oil from these wells, as no written record exists; but information was received regarding 144 wells, from which it is deduced that the minimum daily production at Twingoung is 20 tons,[1] and at Beme, 6 tons; or 26 tons in all. From this it is calculated that there is produced from each full-working well an average of 400 lbs. daily, the wells of greater depth being, on the whole, the more productive. The gradual decrease in the amount of production from the wells is, as may be conjectured from their shallowness, well marked, though the data necessary to establish the precise rate of decline are by no means reliable. From figures obtained from sixteen wells, it appears that, after the first year of working, the production had declined 25 per cent.; while during the fifteenth year the annual decrease was irregular but not more than 5 per cent. of the original output.

These oil-wells have been a source of great wealth to the natives, and on every side a feverish unceasing industry is apparent. But the labour is conducted without method and without the necessary persistence, and everywhere either overhasty or neglected work can be observed. The native appliances are of the most primitive character. The wells, 4 feet square, are excavated by means of an instrument consisting of a wooden handle with an iron shoe, a drawing of which is given on the plate attached; the earth, and eventually the oil, being brought to the surface by means of a leather rope passing over a drum, the axis of which turns on rough, naturally-grown, forked supports. The cost to the natives of sinking a well 300 feet deep, calculated on the basis of well-established facts, is given as £210; the probable daily average output of oil from which is 584 lbs., or say 73 gallons. The crude oil sells, in the neighbourhood, at slightly less than 1*d.* a gallon, and the production of such a well is worth 5*s.* 8*d.* per day, or £102 per annum.

The following is an instance of the profits made by the proprietors of such a well, the outlay being £210, and the expenditure for one year's working:—

	£.	s.	d.
Loss, breakage, holidays, &c.	15	6	0
Wages and other necessary expenses	15	6	0
Amortization in ten years, 10 per cent. of cost	21	0	0
Total	51	12	0
Value of oil produced	102	0	0
Balance	50	8	0

or equal to 23·6 per cent. on the capital, with amortization in ten years.

While no increase in the production of oil need be expected from wells sunk by natives, owing to their inability to pierce to a sufficient depth, it is confidently expected that large quantities of oil would be obtained from bores worked according to European style, and in such numbers as would thoroughly drain the strata. From such it is estimated that at least 80 tons per day might be raised in the Twingoung field alone; while in the area, estimated at 65 acres, situated between the two existing oil-fields, on which Messrs. Finlay Fleming and Co. have commenced operations, it is judged that from two bores per acre, sunk to a depth of 400 feet, 50 tons per day might be extracted.

---

[1] The conversion into English weights is calculated on the basis of 1 viss = 3·65 lbs. as given in the report.

It may be safely concluded that the minimum production per square mile will be 500 tons per day; and as there are included in the lease of Messrs. Finlay Fleming and Co. 16 square miles of valuable oil-bearing ground, at least 800 tons (*sic*)[1] of oil per day can be obtained from this.

Owing, so far as is known, to the absence of pressure, the oil will in all likelihood require to be raised by means of pumps; yet it is not improbable that flowing wells may be tapped by bores sunk at some distance from the centre of the anticline, and therefore at such a depth as would prevent the escape of the confined subterranean gas.

There is every reason to believe that the production of oil in this district will develop eventually into an important industry; but wild ideas of competition with American or Russian oils are to be deprecated.

R. H. B.

Magnetic-Iron-Ore Mountains of North Sweden and the Ural.

By — von Schwarze.

(Zeitschrift des Vereines deutscher Ingenieure, 1889, p. 783.)

In this communication the Author gives a comparison between the Swedish and Uralian magnetic ore deposits, showing the points of similarity and contrasts.

The most southerly of the Swedish deposits under consideration is that of Gellivara in 67° N. lat. Here the ore occurs in narrow ridges projecting from a gently sloping high plateau. It is very highly magnetic, much mixed with apatite, and contains up to about 5 per cent. of red iron ore. It is considered to be the product of alteration of a phosphoric hematite which has gradually become changed into magnetite, the phosphoric acid at the same time combining with lime to form crystallized apatite. This is considered to be proved by the circumstance that both kinds of ore are equally phosphoric, while apatite is only apparent as such in the hematite. The Author, however, points out that in Southern Sweden the reverse conditions prevail, as for example at Grängesberg, where the siliceous hematite of the bottom of the deposit contains only 0·10 per cent. of phosphorus, while the magnetite forming the upper portion contains 0·5 to 0·8 per cent. and even more. He thinks that some of the phosphorus may be present as wavellite (phosphate of alumina), which he has found in the Ural mines, but which does not appear to have been noticed by Swedish observers.

---

[1] While it is possible that the Author may not deem each of the 16 square miles as capable of yielding 500 tons per day, he gives no data leading to any other conclusion; therefore the figure 800 is probably an error in calculation for 8,000.

The Gellivara ore varies from a little below 60 to above 70 per cent. of iron, and in phosphorus from 0·1 to 1·7 per cent.; it is almost free from sulphur and manganese, but in places contains titanium up to 2 per cent. The available quantity cannot be determined with certainty, as the relation of the ore to the red gneiss enclosing it has not been made out. In any case very large quantities may be got without undertaking any subterranean workings.

More remarkable in character are the Kirrunavara and Luossavara Mountains in 68° N. lat., which are separated from each other by a small lake 890 metres broad. The former range rises in a bold ridge to a height of more than 200 metres above the plain, its longitudinal extension north and south being 4,150 metres. The ore is exposed in cliffs, often several hundred feet high, with a talus of sand and gravel, with fallen masses of ore at the base. The deposit has a slight easterly dip between walls of grey and red felsite porphyry, and is about 215 metres thick in the broadest part. It yields from 62 to 73½ per cent. of pig-iron, and contains 0·04 per cent. of phosphorus in the northern and southern parts, and 1·3 per cent. in the middle. The extreme part contains 86,127,000 tons, and that covered with gravel 174,331,700 tons above the level surface, and in depth it is considered likely to yield 1,510,000 tons per metre of sinking.

The Luossavara Mountain is similar in general character to that of Kirrunavara, but is of a less imposing development, being smaller and conical in form. The exposed range of ore is computed to contain 27,656,000 tons, and the yield per metre in depth 239,000 tons, or considerably less than the neighbouring deposit. It is, however, very much purer, yielding 70 to 73 per cent. of pig-iron, while the phosphorus is reduced to 0·003 per cent. In both deposits, therefore, about 85,000,000 tons of ore of the highest Bessemer quality are available above the level of free drainage; but to bring them into the market, extensions of the Lulea-Ofoten line, the only one at present available, will be required.

The magnetic ore mountains of the Siberian Ural, unlike those of North Sweden, which are still unutilized, have been actively worked for more than one hundred and fifty years. The most important of these, the Blagodat (Hill of Benevolence), is situated at Kuschwa, a station on the Perm and Jékaterinenburg Railway. It was discovered in 1730 by a man named Putschkin, who sold it to the Russian Government for half-a-guinea, and was burnt alive by the Wogul aborigines, who feared that the introduction of mining works would, as it actually did, lead to their expulsion.

The deposit, which was formerly much higher, rises to 500 feet above the Salva River. It is a very pure magnetite (65 per cent.) in porphyry, and is almost free from phosphorus. The pure ore is strongly magnetic and polar, several large bodies of such ore being seen surrounded by water, which, although quite clear, has a peculiar violet colour. The magnetite passes on the exterior into brown iron ore, and not into hematite as in Sweden. At the present time the working is not as active as formerly, it being limited to supplying three blast-furnaces at Kuschwa. The surveys and maps are very imperfect, so that there are not sufficient data for calculating the available amount of ore with any approach to accuracy, but there is no doubt that it is very considerable.

The second great magnetite mass of the Ural is near Nischne Tagil, also on the same line of railway. This is longer and broader than that of Blagodat, but so far as regards the magnetic portion it is practically exhausted above the ground-level. It is very actively worked by Prince Demidoff for the supply of furnaces in the neighbourhood and at Jékaterinenburg. The bottom of the workings is now 200 feet below the surface, and the ore is drawn to the surface in carts by horses along spiral roads. More than two hundred horses are in use. The ore at the surface passes externally into brown ore, and into hematite in the deep workings; the containing rock is diorite. The deposit is divided by a bed of mica schist 200 to 300 feet wide, which in places carries a valuable proportion of copper ores and is largely worked. The iron ore contains 65 per cent. of iron and 0·05 per cent. of copper. A somewhat similar association of magnetite with copper over a mica schist is noticed as occurring at Soappavara near Luossovara.

H. B.

The Arroyo Seco Gravel (Gold) Mine.

(Report of the State Mineralogist, California, 1888. Sacramento, 1889. P. 97.)

This mine, situated about 3 miles north of Ione, in Amador County, California, is worked by a method which is said not to have been previously used elsewhere. The claim is 2,700 feet long, with an average width of 1,700 feet of the valley of a dry creek, and contains a bed of auriferous gravel averaging 4 feet in thickness, which is covered by about 26 feet of barren gravel and loam. This cover is stripped by means of a grab dredger attached to a derrick, projecting from the end of a car running on a railway of 16 feet gauge. The car contains the boilers, and can be moved forward as the excavation proceeds. The excavating part has six triangular cutting segments, which close to a hemispherical bucket of about 2 cubic yards capacity. The closing of the grabs is effected by a steam cylinder, which acts directly upon the segments by means of link rods. As soon as the bucket has reached the gravel, steam is admitted below the piston by a five-way valve, which causes it to rise and close the grabs. When lifted a further movement of the valve admits steam above the piston, and discharges the contents of the buckets, and by turning still further the exhaust-passage is opened and the steam escapes.

The lift is effected by a steel-wire rope 1 inch in diameter, and a pair of 9 by 12-inch engines. The projecting boom of the derrick is made of Oregon pine 12 by 18 inches at the foot, 12 by 24 inches in the middle, and 12 by 12 inches at the top. It is 114 feet long, and rises 58 feet above the ground at the outer end. The effective lift of the derrick is about 45 feet above the ground. The lifting capacity is about 7 tons, but the load usually carried is about 2 cubic yards, varying in total weight from 1,550 lbs. in mixed gravel and loam to 3,160 lbs. in clean gravel. The interval between the lifts varies from forty-five seconds to two minutes, according to the height of lift, and the distance swung. The total weight of the derrick car, including two boilers, and the lifting engines, is from 75 to 80 tons. The rails are laid upon heavy Oregon pine timbers of 12 by 16 inches section, the length of line in use being twice that covered by the derrick. As the latter advances the line behind is taken up and relaid in front, or the reverse, if the movement is backward.

The mining operations are carried on principally in the dry season, when the mine has about 40 inches of water to contend with daily, but during the winter floods this increases to 500 or 600 inches. At one end of the claim, a pit 36 feet deep is placed, containing two centrifugal pumps driven by water-power, under a pressure of about 29 lbs. to the square inch; one pump only is worked at a time.

From the bottom of the pit, 33 feet below the surface, a culvert, 14 by 20 inches, is started on the bed rock, and carried on as the work progresses, with a slope of $\frac{1}{4}$ inch in 12 feet up to the face of the excavation. The pumps are submerged and placed on the rock at the bottom of the pit. Another culvert, of similar section at a higher level, carries the sluice water to the pump pit. The bed-rock culvert is kept open by a screen over the upper end. When water becomes scarce for washing the gravel, a portion of that lifted from the mine is conveyed back in pipes to the sluices. The culverts have branches at right-angles running to the face, or every direction where work is going on. In the autumn a penstock is built at the head of each of the different culverts, and in the spring the latter are further extended as the work progresses. The overburden is piled to a height of 45 feet above ground, and the workable gravel is washed in sluices in the ordinary way. These are laid at a slope of 7 inches in 12 feet, with laths 3 by 2 inches on the bottom laid flat through their entire length. From 1 oz. to 2 oz. of mercury is sprinkled over the surface of the sluice at intervals of two to four hours. The total annual loss of mercury does not exceed 25 lbs., most of it being due to retorting in the open air. The gold is what is termed fine gold; it occurs in flattened grains, sometimes attached to small particles of quartz, and varies from 852 to 872 in gold fineness. The size of the excavation made in two months' work was 800 feet in length, with an average breadth of 60 feet, and a depth of 30 feet. From twenty-five to thirty white miners and fifty Chinese miners are employed working day and night; the value of the gold produced varies from 6,000 to 12,000 dollars per month. The mine has been worked by the present method for about four years. The two derricks in use cost about £2,000 each, but they can now be built for a much smaller sum. They consume about 4½ tons of coal each per day.

H. B.

Method of Treating Gold Ore at Deloro, Canada.

By J. E. Rothwell.

(Report of the State Mineralogist, California, 1888. Sacramento, 1889. P. 842.[1])

At Deloro, the ore treated is an arsenical iron sulphide in a gangue of quartz and calcide. It contains about 42 per cent. of arsenic, 20 per cent. of sulphur, and 38 per cent. of iron. On arriving at the mill, the ore is crushed in rock breakers and Cornish rolls; it is then sized and concentrated in jigging machines. The concentrates are roasted in two large Howell-White revolving cylinders. In the first, a preliminary roasting is carried on, and in the second the ore is roasted sweet. The ore falls from the lower end of the second cylinder, and, when cool, is sent to the chlorinators. These are cylinders of ¼-inch boiler-iron, lined with 20-lb. sheet-lead. The truck from the cooling-floor is raised to a platform over the chlorinators, and the charge of chloride of lime is placed on the top of the ore. Water is measured into the cylinder first, the proportion being 120 gallons to the ton of ore, and then the contents of the truck are let in; sulphuric acid is then poured in through a funnel, the cover fastened on, and the cylinder started revolving. After from one and a-half hour to three hours the excess of gas is drawn off, and an exhaust-pump attached to produce a partial vacuum. In this way most of the free gas is removed. The cover of the discharge-aperture is rapidly removed, and the charge emptied on to a sand-filter in a tank with a tight-fitting cover and exhaust-pipe. A better method is to wash the charge in the chlorinator until the liquor decanted into settling-tanks shows no sign of gold. A charge of 3 tons may in this way be washed in two to three hours, while a 1-ton charge on a sand-filter requires six to eight hours. From the settling-tanks and filters, the clear solution is run into precipitating tanks, where it is treated with sulphuretted hydrogen, generated from equal parts of paraffin and sulphur in a small cylinder of heavy boiler-iron. The gas first passes into a receiving-tank to collect the volatile oils; thence it is forced through the solution to be precipitated. When the precipitation is complete, the tank is allowed to stand for a short time, and then the solution is allowed to flow through pressure-filters. Three of these small filters will empty a 1,500-gallon tank in three to four hours, and leave it ready for another precipitation; or the precipitate can be collected in another filter-press, pressed into cakes, dried, roasted, and melted with borax. By means of this process, 96·16 per cent. of the gold in the ore is extracted.

---

[1] The original is in the Library of the Institution.

B. H. B.

The Smelting of Gold and Silver Ores at Argo, Colorado.

By Richard Pearce.

(Advance proof, Transactions of the American Institute of Mining Engineers, Presidential Address, Denver, June 1889.)

The modification of the Swansea system of smelting gold and silver ores used at Black Hawk, Colorado, in 1875, as described by Egleston,[1] has been so far changed as to be scarcely recognizable, except as regards the general principles. The following is a short sketch, without entering into details, of the system now practised at Argo, near Denver, where the works are situated.

The materials smelted include gold and silver ores, and concentrates both pyritic and siliceous, as well as some containing baryta, arsenical copper ores from Utah, and copper regulus from Montana, and the lead smelting works of Colorado. About 200 tons are smelted daily, averaging, silver 40 to 60 oz., gold ½ to 1 oz., per ton, and 2 to 3 per cent. copper, the latter metal being restricted to about 10 per cent. of the ores, while the remaining 90 per cent. is non-cupriferous.

One-half of the ore, or 100 tons per day, is roasted partly in calciners and partly in kilns, but the operation is not pushed to an extreme, from 5 to 7 per cent. of sulphur remaining. The other 100 tons are treated without roasting. Arsenical ores retain a very considerable portion of their arsenic after roasting, and the Author gives details of experiments showing that the removal of arsenic cannot be effected when coal is added to assist in its volatilization by reducing it to the metallic state, unless the ore be heated to the melting-point of arseniate of copper, which is far above the temperature necessary for roasting.

The roasted and siliceous ores are mixed to yield a slag containing about 40 per cent. of silica, and a first regulus, or ore-furnace metal, assaying, copper 40 per cent., silver 400 oz., and gold 6 oz., per ton. The reverberatory furnaces, which are larger than the ordinary South Wales fusion furnaces, have a thin bed, cooled by a flue below, which supplies heated air to the fuel on the firebridge.

---

[1] Transactions of the American Institute of Mining Engineers, vol. iv., p. 276

The capacity is about 25 tons of ore per day, or a total burden of 27 tons, the difference being due to the rich slags added from later operations. About 13 tons charged yield 1 ton of regulus, which always contains some lead, but rarely more than 10 per cent., replacing iron. When lead is present in larger quantity, it is apt to liquate into more and less fusible portions; and the former finding its way into the hearth, carries down a large proportion of gold and silver with it.

The ore-furnace metal, after roasting, mixed with half its weight of unroasted metal and sufficiently rich siliceous silver ores to prevent corrosion of the furnace by the iron, is concentrated to white metal with 60 per cent. of copper. The furnaces in which this operation is performed stand about 3 feet above the level of the ore-furnaces, so that the slag from the former may, when skimmed, flow directly into the latter, where it is cleaned, thereby saving the cost of remelting these rich slags.

The concentrated white metal contains 60 per cent. of copper, 700 to 800 oz. of silver, and 10 oz. of gold, per ton, 1 ton representing 20 to 21 tons of ore. It is crushed to pass through a screen of 6 holes to the inch, and roasted for twenty-four hours. This expels the bulk of the sulphur, forming oxide of copper, but sufficient is retained to produce sulphate of silver in the next roasting. After cooling, it is ground under edge-rollers to 60-mesh size, and is then ready for fine-roasting or conversion of the silver into sulphate.

Fine-roasting process.—This is divisible into several stages, which together last about five hours. In the first stage a low temperature is maintained for about an hour and a half, copper disulphide and dioxide being oxidized with evolution of heat. In the second stage, at a slightly increased temperature for an hour and a half, the charge increases in volume and becomes porous from the formation of cupric sulphate, which is decomposed, and fully changed into cupric oxide in the third period. This lasts about an hour, or until the silver is "out," *i.e.*, fully changed into sulphate. If suboxide of copper is present at this stage, it will, when water is added, cause the reduction of metallic silver from the sulphate in washing vats, and therefore the charge is vigorously stirred and turned over during the final or fourth stage to completely oxidize any cuprous oxide remaining unchanged.

The results of the operation are very materially affected by arsenic, antimony, and bismuth, which form insoluble silver compounds; and of these bismuth is the most prejudicial, giving more trouble than all the other metals together. An insoluble sulphate of bismuth and silver is formed, which increases the proportion of silver in the residues. Under ordinary conditions of working, these residues should contain, after the removal of the sulphate of silver, about 40 oz. of silver per ton; but as they are subjected to further treatment, a few ounces more makes very little difference in the final result.

The lixiviation of the roasted metal is effected with hot water in tubs; the solution of sulphate of silver flows over copper plates for the precipitation of the silver, which requires but little attention. The liquors entering tank No. 1 charged with silver leave No. 2 charged with copper, and without a trace of silver, and finally pass over scrap-iron, which precipitates the copper.

In the precipitated silver some copper is found, partly as metal, and partly as suboxide. This is removed by prolonged boiling with water containing some sulphuric acid, into which air is injected by a steam-jet aspirator. The copper sulphate formed is carefully washed out of the silver, which is then dried and melted into bars, whose fineness averages 999.

The residues from the silver extraction contain about 55 per cent. of copper as cupric oxide, 40 oz. of silver, and 10 oz. of gold, per ton, as well as associated metals, such as lead and bismuth as sulphates, and iron as ferric oxide. They are mixed with pyritic ores containing gold, pyrites rich in sulphur and poor in silver, and quartzose gold ores, and are smelted to a 65 per cent. copper regulus, or residue metal, containing 10 to 15 oz. of gold, and 80 oz. of silver, per ton. The slag, which is of about the same composition as that of the ore-furnace, is thrown away.

The next process is similar in character to that used in making best selected copper. About 12 tons of slabs, the metal from the last operation, are placed on the hearth of a large reverberatory furnace; the openings of the furnace are closed, except two large air-ports near the bridge, and a gradually-increasing heat is maintained for about seven hours, or until the whole mass assumes a semi-pasty condition. The ports are then closed, and the fire is urged until the charge is completely melted. In the last stage, reaction takes place between sulphide and oxide, and a certain amount of metallic copper is liberated, which contains nearly all the gold, as well as the other metals, lead, arsenic, antimony, bismuth, &c. The charge is tapped into sand moulds, and the first few pigs nearest the tap-hole are found to contain plates of this impure copper, commonly known as metallic bottoms. The proportion of these to the whole yield of regulus, or pimple metal, is about 1 to 15. The bottoms contain 100 to 200 oz. of gold, and about 300 oz. of silver, but the amount varies with the impurities, especially lead and bismuth. The larger the proportion of these metals, the more readily is the gold taken up by the copper. The crude bottoms are subject to processes of refining and separation, whereby the gold is recovered, but the details of these are not made public.

The pimple metal, if the operation has been properly performed, contains only 0·1 to 0·2 oz. of gold per ton, in addition to 90 oz. of silver, and 77 per cent. of copper. It is crushed and roasted to form sulphate of silver, and treated in every way like the original white metal; but, as it contains no gold, a separate set of furnaces is used. The residues consist almost wholly of oxide of copper, with an amount of silver not exceeding 10 oz. per ton. It is dried, packed in barrels, and sold to manufacturers of sulphate of copper, or it may be reduced to blister copper by melting it with small coal slack in a reverberatory furnace, which is refined in Massachusetts, and converted into ingot copper for sale. H. B.

The Development and Present Condition of Puddling in Gas-Furnaces. By E. Goedicke.

(Stahl und Eisen, 1889, p. 554.)

The regenerative gas-furnace has of late years been very successfully adapted to puddling in the ironworks of the Austrian Alps. After discussing the earlier forms of furnace, including those of Siemens, Borbély and Price, the Author proceeds to describe that of Springer, which is now largely used. This furnace, introduced in 1883 at Volklingen on the Saar, is a large Siemens furnace, having its regenerators built in two square blocks above the ground-level, and two double puddling-furnace beds placed between. These beds are about 6 feet 4 inches broad, and 6 feet 2 inches long, and are only separated by a narrow throat-flue of the breadth of the iron framing of the bed. Each takes a charge of 10½ cwt., and they are worked alternately, the flame passing first over the bed in use, then over the second, which contains the materials of the next charge, and finally through the regenerators on the chimney side. When the charge is finished and the balls have been removed for shingling, that in the second bed is already melted, so that on the reversal of the flame, the boiling period commences at once. In this way a very large production is realized; from 6·2 tons to 7 tons of best, and as much as 8¾ tons of common iron, being obtained in the turn of twelve hours, the number of heats varying from 13 to 15 in the former, to 16 to 18 in the latter case. The loss experienced is 1·5 to 2 per cent. on the weight of the charge in the best work, but may be as much as 5 per cent. when the furnace is driven hard. The consumption of fuel varies with the quality, being from 45 to 50 per cent. for the best large coal, 57 to 65 per cent. for small slack and 60 to 70 with lignite. In addition to this, from 20 to 25 per cent. is required for raising steam, as the stack boilers of the old puddling furnaces are of course done away with.

The form of construction described above, with regenerators above ground, although advantageous in many ways, and more particularly in allowing the regenerators to be easily opened for cleaning, has the defect of requiring a very long gas-passage between the top of the regenerator and the point of combustion, and therefore, in the newer furnaces, the regenerators are placed underground and at right-angles to the furnace proper, an air-space being interposed between the roof and the ground, to prevent excessive heating by radiation. By this arrangement the length of the furnace is reduced from 42 feet to 29 feet. The tops of the air- and gas-ports and the beds are covered with strongly curved roofs, making capacious combustion chambers. The cast-iron frame-plates are protected by layers of magnesite bricks, which are also used to bring the bridges to the proper height. These latter require renewal after two or three turns. The regenerators require cleansing at intervals of twelve to fifteen weeks; they are filled with bricks measuring 12 by 6 by 3 inches (Austrian). One third of the filling is in Dinas bricks, a second third in ordinary clay fire-bricks, and the last third is common building bricks. When the heating is done with large coal, two slack producers, with a total grate surface of 2·6 square metres, and capable of gasifying 3 tons of fuel in twenty-four hours are required; but with small slack, four step-grate producers, 4 square metres of surface are necessary, the consumption being increased to 76 cwt. In the former case the grates require to be thoroughly cleaned at intervals of eight hours, but with the step grates and dirtier fuel, one producer must be cleaned every two hours. This is done during the balling period, when the demand for gas is less than at other times, and the furnace is at its hottest. When puddling white charcoal iron and a proportion of greyer coke-melted metal, about fourteen heats of 10·4 cwt. are obtained in twelve hours, from 2 to 3 cwt. of cinder being required for fettling. The rabbling of the charge lasts from twenty to twenty-five minutes, making up the balls fifteen minutes, and their removal ten minutes, giving a total time of about fifty minutes for the heat. At this rate there is time for 14 heats with twenty minutes to spare in the turn of twelve hours. These figures refer to pig-iron free from phosphorus. At the Hermannshütte in Bohemia, where the metal contains 1·7 per cent. of phosphorus, only 10 to 12 heats can be got in the turn of the iron if it is to be properly purified.

From the rapid nature of the work in these furnaces, it has been found better to reduce the turn from twelve to eight hours, so as to give the puddler sixteen hours' rest out of the twenty-four. In this way at one work a notable increase in yield and economy of material has been obtained, taking the average output of the year 1887.

FURNACE with SLACK PRODUCER.

——	Twelve Hours.	Eight Hours.
Yield per turn	6·77 tons	7·21 tons
Charge per cent. . . .	102·24	101·20
Coal per cent.	60·20	37·70

FURNACE with LARGE COAL PRODUCER.

——	Twelve Hours.	Eight Hours.
Yield per turn	7·06 tons	7·90 tons
Charge per cent. . . .	102·04	101·20
Coal per cent.	47·00	42·00

Another system of furnace described by the Author is that of Jullich, which is used at some works in Bohemia, consuming brown coal from Dux. This is essentially a combination of two large puddling furnaces placed side by side with a dividing wall between them, having a system of regenerators common to both. The flame is divided over the two beds which are heated simultaneously, and unites to pass through the regenerators on the chimney side. The charge is worked on one bed, while that on the other is being melted down, and as soon as the first is finished, the workmen go over to the opposite side when the second charge is ready for boiling. This furnace combines many of the advantages of that of Springer, but is rather more extravagant in fuel. The average results obtained with 9 cwt. charges were 13½ heats in 5·81 tons in twelve hours, with 103·4 per cent. of pig-iron and 59·2 per cent. of coal.

The last furnace described is that of Pietzka which has been introduced at Witkowitz in Bohemia, and Schweshat in Austria. This has two beds like that of Springer, but is not regenerative, being heated by a grate fire with forced draught and heated air, while the exhaust flame passes round a stack boiler in the ordinary way. The bottom plates of the furnace are carried upon longitudinal-girders, which are supported by a central ram placed below, so that the whole working part of both beds between the fire and flue bridges can be lowered clear of the roof, and turned half round in the horizontal plane. In this way the first charge on the bed at the flue end, which has been melting down during the puddling of that at the fire-place end, is brought into the working position as soon as the latter is finished. With 10 and 11 cwt. charges 6·1 tons were obtained per turn at Witkowitz, and 6·4 tons at Schwechat for 106·6 per cent. of metal and 66·5 per cent. of coal at the former, and 105·4 per cent. and 55·8 per cent. at the latter place. In August, 1887, the consumption of coal was as low as 48·9 per cent., which the Author considers to be the most economical results yet attained in a grate-fired puddling furnace, as about one-half of that quantity, 27 per cent., was consumed in raising steam, leaving only 28·84 per cent. for the work of puddling proper.

H. B.

Basic Steel and the Canalization of the Moselle. By A. OELWEIN.

(Wochenschrift des österreichischen Ingenieur- und Architecten-Vereins, 1889, p. 197.)

In explaining the connection between basic steel and the canalization of the Moselle River, the Author points out how injuriously affected the iron industries of the Lower Rhine and Westphalia have been of late years by these three events: (1) The invention of Bessemer which necessitated a thorough change and modification in the works; (2) The annexation of Alsace and Lorraine which has brought about severe competition; and (3) the application of the Thomas Gilchrist basic process of manufacture which utilizes the ores of iron containing phosphorus. It is stated that 60 per cent. of the whole amount of basic steel produced between the 1st of November 1887 and the 31st of October 1888, in Germany, Austria, England, France, Belgium and other countries, was manufactured in Germany alone, and that consequently the demand for suitable iron ores containing phosphorus has largely increased.

The districts of Luxemburg and Lorraine on the Upper Moselle contain inexhaustible beds of these ores, and the Minette beds estimated at about 2,400 million tons, are the most celebrated ironstone beds in Mid Europe. The Lower Rhine and Westphalia are equally rich in coal, and to connect these two industries by means of a practicable water-way in the Moselle for vessels of 500 tons burthen, has been a source of strife for years amongst the various works in the neighbourhood, each fearing the result of competition: namely, on the one hand the iron industries on the Lower Rhine and in Westphalia, and on the other, the owners of mines and smelting-works on the rivers Saar, Lahn, Dill and Sieg. It is stated that of 6,300,000 tons of ore which were smelted in Prussia, 3,500,000 tons only were furnished from local sources, the balance being imported from abroad, and it is added that when the Lower Rhine and Westphalian blast-furnaces were in want of 1,500,000 tons of iron ore, nearly half that quantity was imported from Spain and other countries, though an almost inexhaustible supply of ore suitable for the Thomas Gilchrist process existed on the projected water-way of the Moselle; but to make up the deficiency from this source would mean a further production of basic steel, and this was viewed with jealousy by opponents, though it would appear from statistical returns that the future increase of the German export trade materially depends on the increase in the production of this material.

The canalization of the Moselle would at once induce the Lower Rhine and Westphalian ironmasters to smelt the Minette ores, which would give a further impetus to the Thomas Gilchrist process, and herein lies the connection between basic steel and the canalization of the Moselle. The upper section of the Moselle from

Diedenhofen to Tronard (57½ miles) was canalized in 1868–72; the project for the section Metz to Coblenz (188 miles) was prepared by the celebrated Engineer Fiedel, and is estimated to cost £750,000.

W. H. E.

Barrel Chlorination. By A. Thies.

(Report of the State Mineralogist, California, 1888. Sacramento, 1889. P. 844.)

The Author describes the method of barrel chlorination as conducted at the Phœnix mines, North Carolina, and the Haile goldmine, South Carolina. After working for two years with the original Mears process, he found that the results were quite as good without pressure, as with the highest pressure. He has, therefore, remodelled the chlorinator by closing up the hollow trunnion, removing the goose-neck and acid-chamber, and substituting a lead valve, connected with the inner lead lining, in such a way that the pressure of free chlorine can be ascertained at any moment. The capacity of the chlorinator is from 1 to 1¼ ton of roasted ore. For the Phœnix ores, 40 lbs. of chloride of lime, and 50 lbs. of commercial sulphuric acid are used per ton of roasted ore. It is found best, however, to add half this charge first, to rotate for three or four hours, and then to add the other half. The Phœnix ore contains a considerable quantity of copper pyrites. At the Haile mine, where the ore is a pure iron sulphide, there are used but 10 lbs. of chloride of lime to 15 lbs. of acid, and 4 tons of roasted ore are treated in two chlorinators during ten hours. With the barrel process, 94 per cent. of the assay value of the ore is extracted. The cost of chlorination by this process depends on the number of tons treated per day. Two men can easily treat 4 tons in ten hours, the cost being as follows:—

	£	s.	d.
40 lbs. chloride of lime	0	4	10
60 lbs. sulphuric acid	0	4	10
Two labourers	0	7	4
One chlorinator	0	8	0
Motive power	0	2	0
Total	1	7	0

or 6*s*. 9*d*. per ton. Adding to this 5*d*. for sulphuric acid for making ferrous sulphate, and 10*d*. for repairs and wear, gives the sum of 8*s*. per ton for chlorination, or 18*s*. 7*d*. for roasting and chlorinizing 1 ton of roasted ore, representing 1⅓ ton of raw iron pyrites. In less than seven hours from the time the ore is in the chlorinator, the solutions are ready for precipitation and the tailings clean. The wear on the inner lead lining of the chlorinators is inappreciable. Indeed, a chlorinator in use at the Phœnix mine for five years shows no sign of wear.

B. H. B.

A General Law of Induction in a Circuit devoid of Resistance.

By G. Lippman.

(Comptes rendus de l'Académie des Sciences, Paris, 1889, p. 251.)

The general equation of a single electric current is—

If the electromotive force is that due only to electromagnetic induction—

$$E = \frac{dN}{dt},$$ N being the total induction through the circuit.

Expressing the quantity $L\frac{dc}{dt}$ also in terms of the induction through the circuit—

$$L\frac{dc}{dt} = -\frac{dN_1}{dt};$$

rewriting (1)—

$$\frac{dN}{dt} + \frac{dN_1}{dt} - cr = 0,$$

taking the case of a circuit devoid of resistance and integrating,

$$N + N_1 = \text{constant}.$$

In words: In a circuit devoid of resistance the induced current is always such that the total induction is a constant. The first result of this is that a circuit of no resistance is impermeable to induction.

The Author gives several other important deductions from this law, and concludes by calling attention to the experiments by Hertz, where the induced electromotive forces are so large compared with the resistance that the latter approaches the limit of an indefinitely small resistance, and which show that under these circumstances the space enclosed by the circuit is impermeable to the induction. Ll. B. A.

Experiments on the Practical Values of Galvanic Batteries.

K. Sosnovsky.

(Jurnal Ministerstva Putei Soobstchenia, 1889, p. 119.)

The Author regrets that there is no system in the present methods of testing batteries, and that they are not tested under those conditions of work for which they are designed, and he proposes a series of experiments by which the true character of any battery would be thoroughly investigated.

Before submitting a given battery to experiment, all its dimensions should be accurately determined, namely, those of the internal and external cells, the amount of liquids (exciting and depolarizing), the area of the electrodes (the active surface of the positive electrode and the depolarizing surface of the negative electrode), the distance between the electrodes and their weight. Having determined these quantities, the electrical values of the battery are next investigated, and the Author enumerates the following points for testing.—

1. The electromotive force and its variations during the action of the battery for a practical length of time.
2. The internal resistance and its variations during a practical length of time.
3. Its depolarizing capacity.
4. Its electrical capacity within the limits of a known electromotive force corresponding to the practical use of the battery.
5. The length of time during which it is capable of working.
6. Its behaviour when out of circuit. The Author then proceeds to describe the various methods of determining these values, giving preference to those which are simplest and easiest of arrangement, although they may not be as accurate as other more complicated means. Experiments illustrating these determinations are described.

Batteries are divided into two classes, those giving large currents and those giving small currents. The first class may be investigated in relation to a larger or less productiveness, or to a larger or less external work.

The battery is then tested from a technical and economical point of view. The technical points to be examined are:—

1. Simplicity, convenience, or bulkiness of construction.
2. If it requires special supervision or works automatically.
3. Facilities for repairing and manipulation.
4. If the materials of which it is made are solid or liquid.
5. If noxious vapours are evolved.
6. The action of the atmosphere on the exciting and depolarizing liquids.
7. If crystals or precipitates are formed.
8. In what condition the battery is after action.
9. The state of the porous cells after action.
10. The influence of temperature.
11. If there is any local action or loss when the circuit is broken.

With a small-current battery it is not important to know the cost of work done, as the quantity of energy expended is small, and consequently the consumption of material is inconsiderable; therefore with batteries of this class the chief consideration is their primary cost.

With a large-current battery for intermittent work, it is most important to know if it keeps on working with broken circuit or not. With large-current batteries working unintermittently the calculation of the cost of work done is most important. First, the theoretical cost of some unit of work, for example, per HP. per hour; and then the practical cost is determined by experiment. These data show the productiveness of the material consumed. The Author deduces the formula $P = 27 \cdot 44 \frac{e \times n}{E}$, where

P = the weight of material theoretically consumed per HP. per hour;
e = chemical equivalent of the material;
n = the number of equivalents taking part in the reaction of the given battery;
E = electromotive force of the given battery in volts for calculating the theoretical cost of working a battery per HP. per hour. Should there be produced by-products capable of utilization, their value must be deducted from the total expenses.

G. K.

The Brush Electric Company's New Alternating-Current System.

(The Electrical Engineer, New York, 1889, p. 338, 5 woodcuts, 1 diagram.)

The system here described is based on the patents of Charles F. Brush and Gustav Pfannkuche, and has many points of interest. The particular dynamo illustrated and described has an output of 60,000 watts, an electromotive force of 2,000 volts, and is run at 1,000 revolutions per minute. The shaft carries two cast-iron disks, each of which supports twelve magnets arranged in a circle with alternate poles; the whole revolving mass weighs 1,700 lbs., and also acts as a fly-wheel. The coreless stationary armature is composed entirely of non-magnetizable material in six sectors, each occupying 60° of the circumference. Each sector is $\frac{9}{16}$ inch thick, weighs 20 lbs., and is made of copper ribbon wound over a porcelain centre-piece with insulating packing at the sides. All the six sectors are coupled in series, and any one can be taken out by a radial slot in the German-silver frame without disturbing the rest, or the entire armature may be removed in two pieces by sliding out from between the poles of the field-magnets, each half weighing only 100 lbs. The fall of potential in the machine from no load to full load is less than 10 per cent., and this result is obtained without compound winding or artificial regulation of any kind, a result said by the Author to be unapproached by any alternator with an iron core in the armature. The twenty-four field-magnets are excited by a small direct-current machine, to which all regulation is applied by means of a rheostat in the shunt-coil of its field-magnets. The larger Brush converter has some noticeable features. The core consists of a polygonal ring of insulated iron wire of the best quality, so wound as to leave several concentric air-spaces; upon each side of this polygon is wound first a single layer of heavy copper wire for the secondary coil, and these are so coupled that the layers on one-half of the core are in series, and the two groups in parallel. There are insulating pads $\frac{1}{8}$ inch thick between the corners of the core and the secondary layer. Over each of the secondary layers are wound a few layers of fine copper wire for the primary, also separated by pads at the corners and air-spaces. The electromotive force of the primary is 2,000 volts, and of the secondary either 100 volts or 50 volts. The Author claims that 98 per cent. efficiency is exceeded in the larger sizes.

An ammeter, consisting of a compensating expansion device, is used, upon the principle of the Brush lamp patent, No. 219,209, September 1879. E. R. D.

A Rotary Commutator for Induced Currents. By P. le Goaziou.

(La Lumière Électrique, vol. xxxiii, 1889, p. 330, 4 figs.)

The object of this commutator is to obtain a direct high-tension current from the secondary coil of a Rhumkorff coil, or other transformer, by passing a low-tension direct current from a primary or secondary battery or dynamo through the primary coil, the commutator itself making and breaking the circuits at regular intervals. It is composed of a cylinder of wood, or other non-conductor, upon the periphery of which are fixed six metal contact-pieces of different lengths; at six different positions on the circumference of this cylinder is placed a pair of brushes, through which a circuit is completed when they both touch the same contact-piece. As the cylinder rotates, the circuit to the secondary coil is first closed, then the primary is closed, so that an inverse current is induced in the secondary coil, which is conducted to the line-wire; the secondary circuit is then opened, while the primary remains closed, producing no effect in the secondary; after a quarter turn, the secondary is again closed, and in the meantime the connections to the line-wire have been reversed; the primary is then opened, and the direct current from the secondary flows into the line-wire in the same direction as the former current. If the currents succeed each other with sufficient rapidity, the effect upon a receiver in the line-wire circuit will be the same as with a continuous direct current. In order to change the direction of the current in the line-wire, it is, of course, only necessary to reverse the terminals of the battery or dynamo. As the inverse current in the secondary is feebler than the direct, the Author makes use sometimes of a simpler arrangement to collect merely the latter with only two pairs of brushes, and states that this system is now under examination by the French Post and Telegraph Department.

E. R. D.

Economical Size of Line-Wire for Constant-Current Circuits.

By — RHODES.

(Advance proof, Transactions of the National Electric Light Association Convention, U.S., Aug. 1889.)

The Author submitted the following formula as that which he himself used :—

Let x = diameter of line-wire in mils, A = length of circuit in miles, B = price of copper per lb., C = cost of power per year per HP., E = amperes of current.

When any plant is about to be established B and E are known, C can be determined near enough for the purpose, and A will be found to be immaterial.

$0 \cdot 016\, x^2$ = lbs. of wire per mile.
$0 \cdot 016\, \mathrm{B}\, x^2$ = cost per mile of wire.
$0 \cdot 0016\, \mathrm{B}\, x^2$ = interest and depreciation at 10 per cent.
$0 \cdot 0016\, \mathrm{A\,B}\, x^2$ = annual cost of wire. (1)
$\frac{54{,}577}{x}$ = ohms per mile.
$\frac{54{,}577\, \mathrm{E}^2}{x^2}$ = watts per mile.
$\frac{54{,}577\, \mathrm{E}^2}{746\, x^2}$ = HP. lost in transmission per mile.
$\frac{54{,}577\, \mathrm{C E}^2}{746\, x^2}$ = cost of same.
$\frac{54{,}577\, \mathrm{A\,C\,E}^2}{746\, x^2}$ = annual cost of power lost in entire circuit. (2)

With any increase of wire the value of (1) will increase while (2) will diminish, and the economical value of x will be such that the sum of (1) and (2) will be a minimum.

Let u = this sum—

$$u = 0 \cdot 0016\, \mathrm{A\,B}\, x^2 + \frac{54{,}577\, \mathrm{A\,C\,E}^2}{746\, x^2}.$$

Differentiating $$\frac{du}{dx} = 0 \cdot 0032\, \mathrm{B}\, x - \frac{109{,}154\, \mathrm{E}^2\mathrm{C}}{746\, x^3}.$$

Placing this equal to zero and reducing, there results

$$x^4 = \frac{45{,}700\, \mathrm{E}^2\mathrm{C}}{\mathrm{B}}.$$

This formula shows that the diameter of wire depends on the price of copper, cost of power, and quantity of current, and is entirely independent of the length of the circuit and the voltage. The differential coefficient shows that the formula is in harmony with Sir William Thomson's rule, that "the additional running expense due to the resistance of the conductor shall equal the interest on its first cost." The Author draws attention to the fact that price of copper refers to bare wire, and then gives examples of the use of the formula.

E. R. D.

Measurements of the Insulation of Porcelain Insulators.

By — SCHOMBURG.

(Centralblatt für Electrotechnik, 1889, p. 543.)

The following measurements give the insulation resistance in various states of the weather and temperature of a double bell insulator, measured with an electromotive force of about 100 volts in Berlin, at a height of 7 feet from the roof:—

Date.	Hour.	Temperature Fahrenheit.	Insulation Resistance.	Remarks.
		°	Megohms.	
March 20 .	5.30 A.M.	75	630	Before sunset dull; during the night cloudy.
" 20 .	12.0	75	58,432	Sunshine.
" 27 .	6 0 A.M.	77	2,016	Before sunset dull; cloudy during night.
May 9 .	5.45 "	81	1,021	A little dew.
" 12 .	5.30 "	82	180	Rather heavy dew.
" 13 .	2 0 P.M.	88	1,051	Pouring rain.

Ll. B. A.

The Suppression in a Special Instance of the Difficulties from Induction and Leakage between Neighbouring Telephone Wires.

By E. MASSIN.

(Annales télégraphiques, 1889, p. 49.)

In the valley of the Suippe there are seven subscribers at Portfaverger and five at Warmeriville, and from the nature of their business, all being competitors, it is important that those subscribers, whose lines run parallel, should not be able to overhear messages relating to one another's business. The subscribers all communicate in the first instance with the town of Reims, and not among one another, and this has been taken advantage of, to get over the difficulty by cutting off the connection of all subscribers but the one having use of the line to Reims. A polarized relay is established at each subscriber's instrument, operated by positive and negative currents from the exchange.

The positive current is used to call subscribers, or to maintain the circuit of any subscriber closed; on sending a negative current the subscriber's instrument is cut off. The operation then is for the central station to call up a subscriber by a positive current, then send a negative current on all those lines it is desired to cut off, and the connection is severed at the subscriber's instrument. This arrangement has proved very satisfactory to the users.

Ll. B. A.

An Experimental Theory of Lead Accumulators.

By Gaston Roux.

(L'Électricien, 1889, p. 411.)

The Author has endeavoured to determine the true reactions on the positive and negative plates of a lead accumulator, by ascertaining the amount of sulphuric acid absorbed by the plates during discharge, and deducing therefrom the chemical operation involved.

The experiments were made on cells of the Julien type in the following manner:—The negative plate was placed in a porous cell filled with acid of known strength, the positive plate being outside the porous cell also in acid of known strength. The plates were slowly charged till gas was just disengaged; the acid was now changed, and fresh acid introduced for the discharge, which was continued till the electromotive force began to fall. The ampere-hours were obtained from the integral curve of current and time. The amount of acid absorbed was then found from the known original volumes and strengths by triturating the resulting liquid with a solution of caustic potash of known strength. The results of a large number of experiments give the following as the weight of normal sulphuric acid absorbed per ampere-hour:—

Negative plate.	Positive plate.	Both plates.
1·410 gram.	2·293 grams.	3·705 grams.

The following equation satisfies these results—

$$\begin{array}{ll} \text{Before discharge} & 4\,(PbO_2) + 5\,(SO_4H_2) + 3\,(SO_4H_2) + 4\,Pb = \\ \text{After} \quad ,, & Pb_4\,(SO_4)_5 + Pb_4\,(SO_4)_3 + 8\,H_2O. \end{array}$$

The experiments therefore point to a sulphating of both plates during the discharge, with a production of water.

The experiments were conducted during the discharge only, because the acid liberated during the charge, in the substance of the plates, takes a long time to disseminate itself in the liquid, whilst the acid is absorbed from the liquid very readily during the charge.

Ll. B. A.

[Note by Abstractor.—Compare these results with those in a recent Paper to the Royal Society, June 20, 1889, by Dr. E. Frankland, "On the Chemistry of Storage Batteries."]

The Consumption of Energy in Electro-Metallurgical Processes.

By H. Ponthière.

(La Lumière Électrique, vol. xxxiii. 1889, p. 251.)

The Author here draws a comparison between the energy consumed in the following modes of treatment. (1) Electrolysis with a soluble anode, represented by the Marchese process at Casarza, near Genoa, and at Pont-Saint-Martin in the Aosta valley. (2) Electrolysis with an insoluble anode. (3) Thermo-electrolysis, represented by the extraction of aluminium from the molten fluoride by the Kleiner process at Tyldesley, Lancashire, the Bernard and Minet process at Creil, near Paris, and the extraction of magnesium from its chloride, at Humelingen, near Bremen, by the Graetzel process. (4) Electro-thermal treatment, represented by the manufacture of cupro- and ferro-aluminium by the Cowles electric furnace, at Lockport, U.S.A., and at Milton, near Stoke-on-Trent, and also by the Heroult electric crucible at Neuhausen, Switzerland. The Author treats the question under three heads: (*a*) Energy consumed, or chemical yield; (*b*) yield of the ore; (*c*) purity of the metal produced.

(*a*) *In process* (1). 2 tons of copper were produced in twenty-four hours from anodes of copper matte, with a composition, in round numbers, of 55 per cent. copper, 38 per cent. iron, and 27 per cent. sulphur. The work produced by the dynamo was 1,963,600 watt-seconds = 1,860 units[1] of heat per lb. of copper, which, admitting 80 per cent. electrical efficiency for the dynamo, is equal to 2,330 units actually used. Breaking and screening the ore, and production of steam for lixiviation, use 0·32 lb. of coal per lb. of copper, or $0 \cdot 32 \times 11,120 = 3,560$ units of heat, so that the total consumption is $2,330 + 3,560 = 5,890$ units of heat per lb. of copper. Considering that the matte is composed in about equal proportions of Cu_2S and CuS, which are to be reduced, about 280 units of heat are theoretically required per lb. of copper, the $CuSo_4$ in solution is partly electrolysed; also a good deal of $Fe_2(SO_4)^3$ is changed to $FeSO_4$, so that only about 70 per cent. of the current is of actual use in precipitating the copper. The result is that about 450 units of heat may be reckoned as the energy theoretically required per lb. of copper, so that the bath alone uses $\frac{1,860}{450}$ = about four times the theoretical energy, and the total consumption $\frac{5,890}{450}$ = thirteen times the theoretical energy required. Allowing that the ordinary treatment of sulphides with 30 per cent. of copper by heat alone requires at least 3 lbs. of coal, or 32,400 units of heat per lb. of copper, the energy used is about $\frac{32,400}{450}$ = seventy times the theoretical energy required.

---

[1] The unit of heat here used is the pound-degree Fahrenheit.

(2) It can easily be shown that the treatment of sulphates of copper by this process requires at least double the energy used for the ores by process (1).

(3) On the Kleiner process, 0·0067 lb. of aluminium is produced per electrical HP. per hour, or 381,060 units of heat per lb. of aluminium; the Minet process gives 0·0447 lb. of aluminium per electrical HP., or 54,450 units of heat used per lb. of metal, the large difference being due to the fact that in the Kleiner process the same material is treated several times. The theoretical energy cannot be exactly stated, but the Minet process is about as efficient as the Cowles, while the Kleiner is about six to seven times less efficient.

(4) The Cowles furnace at Lockport produced 0·03 lb. of aluminium per electrical HP.-hour, and used 4 lbs. of charcoal and carbon electrode per lb. of aluminium produced. The first is equivalent to 87,950 units of heat, and the 4 lbs. of carbon, burnt into CO, give 4 × 4,469 = 17,850, in all 105,800 heat-units per lb. of aluminium. At Milton the result was 63,420 heat-units per lb. At Neuhausen, by the Heroult process, the result was 39,850 units of heat per lb. of aluminium. The heat of formation of Al_2O_3 is about 12,850 units per lb. So that at Lockport $\frac{105,800}{12,850}$ = 8·2 times the theoretical energy was used; at Milton $\frac{63,420}{12,850}$ = 4·9 times; at Neuhausen $\frac{39,850}{12,850}$ = 3·1 times. The Author states that there is no reason why the Cowles continuous furnace should not be as efficient as the Heroult process, and then gives particulars of the Deville process, which uses about 45·6 times the theoretical energy required; and he remarks that the energy used with the Catalan furnace in reducing iron ores is about 5·9 times the theoretical energy, and that this is about double of that required with the blast-furnace.

(*b*) *Yield of the Ore.*—By the Marchese process, about 92 per cent. of the metal is obtained; by the Kleiner, about the same; in the Cowles furnace, and in the Heroult process, about 66 per cent.

(*c*) *Purity of the Metal produced.*—99·7 per cent. of pure copper is guaranteed by the Marchese process; the aluminium obtained by Messrs. Bernard and Minet is almost pure; by the Cowles or the Heroult process the aluminium always contains at least 10 to 15 per cent. of silicon.

In conclusion the Author states that from the point of view of energy used, the electro-metallurgical processes are superior to the ordinary ones, with the exception of process (2); but for purity of the metal produced process (4) is much inferior to the other three. He therefore classes them as follows in order of merit: Thermo-electrolysis, electrolysis with a soluble anode, electro-thermal processes, leaving out altogether electrolysis with an insoluble anode, as being too wasteful.

E. R. D.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1888-89.—PART IV.

Abel, Sir F.—*Discussion on Armour for Ships*: Influence of high explosives on the design of future war-ships, 48.

Abouchoff Works, St. Petersburg, description of the fluid compression of steel by hydraulic pressure, at the, 83 *et seq.*

Abstract of receipts and expenditure, 220.

Accumulators, lead, an experimental theory of, 491.

Adams, T., balanced slide-valves of, used on the North London Railway, 369.

———, W., form of bogie adopted by, on the South Western Railway, 301.

Admiralty programme, 1889.—"*On the New Programme for Ship-building,*" W. H. White (S.), 375.

Air-renewal in inclosed spaces, the employment of carbonic-acid gas for the determination of, 445.

"Amiral Baudin," French armour-clad, 5 *et seq.*

Anderson, J., elected associate member, 82.

———, W.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* The Abouchoff works, St. Petersburg, 180.—Permeability of heated metals by gases, fluids, and solids under pressure, 181.—Rationale of fluid compression, 181.—Steel-ingot casting at the Abouchoff works, 183.—Elected member of council, 206, 249.

Annable, W., his paper on the compression of fluid steel, 152.

Annual general meeting, 205.

Anzorena, J., admitted student, 82.

"*Armour for Ships,*" Sir N. Barnaby, 1.—Uses and nature of armour, 1.—Phases of armour in the French Navy: First period, floating batteries, 4.—Second period, sea-going armour-clads.—First phase, 4; second phase, 6; third phase, 7; fourth phase, 7; fifth phase, 8.—Use of high explosives, 8.—Quick-firing guns, 10.—Table of speeds of war-ships of different nations, 12.—Design for a battle-ship of 3,200 tons, 12.—Relative advantages of few ships of large size and many ships of small size, 14.—Armour, 15.—Mode of manufacturing thick armour-plates: Cammell's process, 15; Brown's process, 16; Creusot process, 16.—Tests of armour-plates, 18.—The question of war-ships an engineering one, 21.—Proposals of the Admiralty for the new additions to the Navy, 22.—*Discussion*: Sir G. B. Bruce, President, 25; Sir E. J. Reed, 25; Sir N. Barnaby, 26, 27, 33, 70; Vice-Admiral Howard, 34; Capt. C. P. Fitzgerald, R.N., 34; Admiral H. Boys, 37; W. H. White, 40, 51; Sir F. Abel, 48; Capt. Orde Browne, 49; B. Martell, 50; E. Robbins, 52; Admiral J. H. Selwyn, 52; Admiral Sir G. Elliot, 55; T. Nordenfelt, 58; T. E. Vickers, 61; S. W.

Barnaby, 62; Dr. W. Pole, 63; Sir F. Bramwell, 70.—*Correspondence:* Admiral Sir J. C. D. Hay, 75; Major D. O'Callaghan, R.A., 78; Rear-Admiral R. A. E. Scott, 80.

————plates, manufacture of, at Sheffield, 15 *et seq.*

Armstrong, Lord, his paper in the "Nineteenth Century" on the Admiralty programme, 74.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* Fluid pressure and forging not the same, 183.—Nature of the defects affecting ingots as they were cast, 184.—The claims advanced for the fluid-compression process not fully proved, 185.

Arnold, J. O.—*Correspondence on the Treatment of Steel by Hydraulic Pressure:* His experience with faulty Bessemer tire ingots, 193.—Mode of drilling faulty steel so as to collect the contained gas, 193.—Mr. Greenwood's tests of shell steel in its soft state, 194.—Telford premium awarded to, 215, 224.

Arnould, P., note on tensile-tests of metals, 412.

Aspinall, J. A. F., Telford premium awarded to, 215, 224.

Atmosphere, micro-organisms in suspension in the, the influence of ventilation on the, 442.

Axle-boxes, radial, used on English railways, 297 *et seq.*

Baker, B., elected member of council, 206, 249.

Balfour, D., transferred member, 82.

Barba, —, experiments made by, at Creusot leading to the belief that great changes of structure took place during the cooling of steel, 148.

Barbette, turret-, on the Canet system for 12·6-inch guns, 463.

Barker, J. H., admitted student, 204.

————, R., elected member, 82.

Barlow, W. H, his experimental cast-iron plate, 313.

Barnaby, Sir N. "*Armour for Ships,*" 1.—*Discussion on ditto:* Explanation of the diagrams illustrating the phases of armour, 26.—His ignorance of the Admiralty proposals for increasing the Navy, when the Paper was written, 27.—Material, "woodite" proposed to be employed as solid raft packing, 33.—Influence of ramming in future naval wars, 70.—Manufacture of armour-plates, 71.—Objections to the use of different kinds of armour in cruisers and battleships, 71.—High explosives, 72.—Objection that his 3,000-ton ships were very small, 73.—The solid-raft body as a protection instead of armour, 73.—Opinions of Captain Reade, R N, and Lord Armstrong on the war-ship of the future, 74.—Mistake of attempting to ignore the criticism of engineers on the construction of war-ships, 75.

————, S. W.—*Discussion on Armour for Ships:* Proposed substitution of solid raft packing for armour at the water-line, 62.—Suggestion that the Admiralty should build merchant steamers according to their own requirements and then hire them to the shipowners, 63.

Barré de Saint-Venant's theory as to the shape taken by the fracture of a broken beam, 309.

Barrel chlorination, 484.

Barrus, G. H., duty-trials of pumping-engines, 434.

Barry, J. W., elected member of council, 206, 249.

Batteries, galvanic, experiments on the practical values of, 485.

Bayly, G. H., memoir of, 387.

Beams. "*Experiments on the Strain in the Outer Layers of Cast-Iron and Steel Beams,*" E. C. de Segundo (S.), 308.—General theories of the strength of cast-iron beams, 308.—Measurement of the strain in the outer layers of beams, 315.—ditto, ditto steel, 323.—Results of experiments on steel, 325.—Notes as to the experiments. *Appendix:* Testing-machines, 333.—Measuring-apparatus, 333.—Test-pieces, 335.—Tables I–XVII. Details of experiments, 337.—Transverse modulus from cast-iron beam, 352.—Extension of outer fibres of cast-iron bars, 352.—Supplementary experiments on cast-iron, 353.

Beckett, W. T. C., elected associate member, 204.

Belcher, W. E. G., admitted student, 204.

"Bellerophon," H.M.S., 69.

Berkley, G., elected vice president, 206, 249.

Bessemer, Sir H., his proposals of 1856 for the fluid compression of steel, 83, 93.—Elected honorary member, 204.

——— steel. See Steel.

Bissell bogie, the, 296.

Black, F. C., memoir of, 402.

"Blake," H.M.S., construction of, 46.

"Blenheim," H M.S., construction of, 46.

Bond, G., elected member, 82.

Boys, Admiral H.—*Discussion on Armour for Ships:* Experiments of the Captain of the "Excellent" in 1880 on iron for ship-building, 37.—Erroneous notions as to the vulnerability of the water-line of ships against artillery, 37.—Circumstance attending the sinking of a slaver as illustrating the difficulties of getting in a shot between wind and water, 38.—Frequent assertion that the question of ships of war was not a naval one, 38.—Breech-loading *versus* muzzle-loading ordnance, 39.—Illustration of the probabilities of an action between a single big ship and four smaller ones, 39.

Brake, Westinghouse, new, quick-acting, experiments with the, on the Baden State Railway, 459.

Bramwell, Sir F.—*Discussion on Armour for Ships:* Protest against the suggestion that the Government should build fast merchant-cruisers and hire them to the shipowners, 70.

Brenner, H., experiments on the removal of mine-gas by exhaustion, 464.

"Brennus," French war-ship, 40.

Bridge, Menai suspension, referred to in the report of the council, 218.

——— (viaduct), Cervena, over the Moldau, 426.

——— ———, Paderno, over the Adda, 424.

Bridges, iron, in Austria, the renewal and reconstruction of, 422.

———, ———, new system of examination for, 427.

British Navy, proposals for new types of ships for the, 11 *et seq.*—"*On the New Programme for Ship-building,*" W. H. White (S.), 375.

Brough, J. W., elected associate member, 204.

Brown, Sir J. and Co., mode of manufacturing compound armour-plates, 15, 47.

Browne, Captain O.—*Discussion on Armour for Ships:* Shells charged with high explosives, 49.—A question of hard *versus* soft armour-plates, 50.

Bruce, Sir G. B., President.—*Discussion on Armour for Ships:* Opening remarks, 25.—Remarks as to the death of Mr. F. C. Stileman, 203.—Vote of thanks to, 205.—Knighthood bestowed upon, as President of the Institution during the Queen's jubilee, 211.

Brüll, A., Godillot's step-grate furnace for burning poor fuels, 438.

Brunel, I. K., dock-improvement at Bristol carried out by, in 1848, 281.

Brush Electric Company's, the, new alternating-current system, 487.

Buchholz, J. A. A., elected member, 82.
Bulmer, P., transferred member, 82.

Cammell, C., and Co., their mode of manufacturing compound armour-plates on Wilson's system, 15.
Campbell, T. P., transferred member, 82.
Canalization of the Moselle. See River Moselle.
Canet's turret barbette for 12·6-inch guns, 463.
Carbonic-acid gas, the employment of, for the determination of the air-renewal in inclosed spaces, 445.
Cast-iron beams. See Beams.
Cement, slag, the manufacture of, 419.
Cements and cement-mortars, permeability of, under pressure, 414.
———— of the Isère, the manufacture and properties of the, 415.
Chads, Sir H., opinion of, in 1850, adverse to the adoption of iron as a material for war-ships, 1, 75.
Chamberlain, H., transferred member, 204.
Chatham, W.—"*The Improvement of the River Avon below Bristol*" (S.), 280.
Chernoff, D., his researches on the structure of steel ingots, 89 *et seq.*
Child, W. S., elected associate member, 204.
China-clay, method followed for removing the air from, 164, 176.
Churruca, E. de, progress of the works of improvement of the Bilbao river, 431.
Clarke, P., admitted student, 204.
Clegram, W. B., memoir of, 388.
Coal-deposits in the Indwe basin and Stormberg range of mountains, report on the, 466.
Cockburn, J. S., admitted student, 204.
Colson, A., transferred member, 82.
Commutator, rotary, for induced currents, 488
Compound armour-plates *versus* those of solid steel, 18 *et seq.*
Compression of steel ingots. See Steel.
Coode, Sir J., K.C.M.G., elected president, 206, 249.
Cooper, S. E., admitted student, 204.
Cottrell, S. B., elected associate member, 204.
Couärd, —, on the duration of steel rails in France, 456.
Council, composition of the, referred to in the report for 1889, 209.
Cowper, E. A.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* Behaviour of molten metal in the gas-furnace, 172.—Nature of the gas occluded in molten steel, 173.—Probable origin of the hydrogen existing in steel, 174.—Excellence of Whitworth steel castings, 174.—Elected member of council, 206, 249.
Cracknell, R. J., admitted student, 204.
Craig, E., elected associate member, 82.
Crampton prize, constitution of the, referred to in the report of the council, 216.
Creosote, the disinfecting properties of, 446.
Creusot mode of manufacturing solid steel armour-plates, 16, 47.
Crimean war, armour-clad floating-batteries used in the, 2.
Cushman. See Goodfellow.

Dalman, J. M., projected international railway through the centre of the Pyrenean range, 453.
Davis, J. H.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* Mis-

taken notion that fluid compression entirely eliminated any flaws that might exist in the ingot, 164.

Davis, W. J. B., admitted student, 204.

Dawe's slide-valves, used on the North London Railway, 370.

Deistler, J., an apparatus for the measurement of strain in ironwork, 428.

Delves-Broughton, V. W., Miller prize awarded to, 206, 225.

Dessendier recording-photometer, the, 449.

Dickinson, A., elected associate member, 82.

Disinfecting properties of creosote, the, 446.

Disinfection of excrementitious substances, experiments on the, 447.

Dolby, E. R., elected associate member, 82.

Donkin, Bryan, jun. "*Experiments on a Steam-Engine, the Cylinder of which was heated externally by Gas-flames*" (S.), 250.—Telford premium awarded to, 215, 229.

Douglas, S. H. W., admitted student, 204.

Douglass, Sir J. N., elected member of council, 206, 249.

Duckham, F. E.—"*Underpinning Great Yarmouth Town Hall*" (S.), 372.

"Duilio," Italian war-ship, 58.

"Dupuy de Lôme," French armour-clad, 5 *et seq.*

Durley, R. J., B.Sc., Miller prize awarded to, 216, 225.

Duty-trials of pumping-engines, 434.

Dwelshauvers Dery, Professor, V. A. E.—Analysis of Mr. Donkin's results of experiments with a steam-engine having the cylinder heated by gas-flames, 251.—"*Investigation of the Heat-Expenditure in Steam-Engines, especially with reference to Methods of Diminishing Cylinder-Condensation*" (S.), 254.—Telford premium awarded to, 215, 224.

Dyer, Col. H.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* His reasons for holding the view that the excellence of the Whitworth pressed steel was quite independent of the treatment by hydraulic compression, 159.

Edge, F. J., elected associate member, 82.

Edwards, W. P., R.N., admitted student, 204.

Electric accumulators. An experimental theory of lead accumulators, 491.

——— current, alternating. The Brush Electric Company's new alternating-current system, 487.

——— ———, constant. Economical size of line-wire for constant-current circuits, 489.

——— ———, induced, rotary commutator for, 488.

——— induction. General law of induction in a circuit devoid of resistance, 485.

——— ———. The suppression, in a special instance, of the difficulties from induction and leakage between neighbouring telephone wires, 490.

——— insulation. Measurements of the insulation of porcelain insulators, 490.

Electro-metallurgical processes, the consumption of energy in, 492.

Elliot, Admiral Sir George, opinion of, in 1876, as to guns *versus* armour, 7.—*Discussion on Armour for Ships:* Small *versus* big ships from a tactical point of view, 55.—Probable effect of torpedoes in influencing naval construction after the next war, 57.—Big ships, big guns, and side armour now obsolete, 57.—Ramming, 57.

Ellis, J. D.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* Alleged unsoundness of ordinary steel ingots not justified, 145.—Apparent unwilling-

ness of the Whitworth firm to grant licenses under their patent, 146.—Recent tests of steel shot made against steel, or steel-faced, armour, 146.

Emery, C. E., Ph.D., Watt medal and Telford premium awarded to, 215, 224.

Emmerich, —, experiments with the new quick-acting Westinghouse brake on the Baden State Railway, 459.

Erichsen, F. O., admitted student, 82.

"**Excellent,**" H.M.S., report of the Captain of, in 1850, adverse to iron for warships, 1, 37, 75.

Excrementitious substances, experiments on the practical disinfection of, 447.

Explosives, high, experiments of naval authorities with, 9 *et seq.*

Farrar, J., memoir of, 390.

Fawcus, A., elected associate member, 204.

Fichtner, —, the peculiarities in the wear of paving-setts, 433.

Fidler, T. C., views as to the ordinary formula for the strength of cast-iron beams, 308.

Fighting-ships for the British Navy, proposed, new types of, 11 *et seq*, 375.

Firth, T.—*Correspondence on the Treatment of Steel by Hydraulic Pressure:* Difference in the temper of the pressed and unpressed ingots tested by Mr. Greenwood, 194.

FitzGerald, Capt. C. P., R.N.—*Discussion on Armour for Ships:* His preference, from a tactical point of view, of one large ship over four small ones, 34.—The money question not of interest for sailors, 36.—Bad policy of building cheap ships, 36.

———, G., elected associate member, 82.

Flangeless wheels, the use of, in the middle of six-wheel trucks, 458.

Fletcher, B. M., admitted student, 204.

"*Flexible Wheel-Bases for Railway Rolling-Stock,*" J. D. Twinberrow (S.), 292.

Fluid compression of steel. See Steel.

Forney, N. M., dimensions of American freight-cars, 306.

Forrest, J., secretary, vote of thanks to, 206.

Fox, Sir D., elected member of council, 206, 249.

Fränkel, Dr. C., the disinfecting properties of creosote, 446.

French Navy, phases of armour in the, 4 *et seq.*

Frend, W. A., memoir of, 403.

Furnace, step-grate, for burning poor fuels, Godillot's, 438.

Furnaces, gas-, the development and present condition of puddling in, 480.

Gale, C. H., elected associate member, 204.—Miller prize awarded to, 216, 225.

Galloway, W., report upon the coal-deposits in the Indwe basin and Stormberg range of mountains, 466.

Galvanic batteries. See Batteries.

Gas-engines, experiments on the speed-variations of, 366.

——-flame heated steam-engine cylinder, experiments on a, 250.

——-furnaces, puddling in, the development and present condition of, 480.

——, mine, experiments on the removal of, by exhaustion, 464.

Gerlóczy, Dr. S. von, experiments on the practical disinfection of excrementitious substances, 447.

Giles, A., M.P., elected vice president, 206, 249.

Girdlestone, J. W., engineer of improvement works in the Avon below Bristol, 290.

"**Gloire,**" French armour-clad, 5 *et seq.*

Gnusin, D., the port of Nicolaieff, 430.

Goaziou, P. le, a rotary commutator for induced currents, 488.

Gobin, A., the manufacture and properties of the cements of the Isère, 416.

Godillot's step-grate furnace for burning poor fuels, 438.

Goedicke, E., the development and present condition of puddling in gas-furnaces, 480.

Gold-mine. See Mine.

Gold-ore. Barrel chlorination, 484.

———, method of treating, at Deloro, Canada, 476.

———, the smelting of, at Argo, Colorado, 477.

Good, C., transferred member, 82.

Goodfellow and Cushman freight cars, the, 305.

Goodman, J.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* Tests of specimens from a Whitworth steel ingot after rolling and forging, 177.—Permeability of red-hot metal to gases or oils, 179.—Appearance of the gases issuing from the ingot in the Whitworth process, 179.—Means of insuring uniformity of temperature of the air-bath in hot-testing, 180.

———, R., admitted student, 82.

Graham, R. W., vote of thanks to, as one of the auditors of accounts for 1889, 206.

Greenwood, W. H.—"*The Treatment of Steel by Hydraulic Pressure, and the Plant employed for the purpose,*" 83.—*Discussion on ditto:* Photograph of the ingots prepared at the Abouchoff works, 185.—Not in any way connected with the Whitworth Company, 185.—Universally admitted existence of an unsound top end of steel ingots, 185.—Alleged monopoly of the hydraulic-pressing plant by two firms, 186.—Operation of liquation on the separation of impurities, 186.—Slow cooling of the ingots, 187.—Success of the process in the production of steel shafts, 187.—Mode of production of blow-holes in the molten ingot, 188.—Alleged greater degree of uniformity in the tables of tests of unpressed than of pressed steels, 189.—Contention that the gases issuing from the ingot-mould originated in the lining, 189.—Alleged ambiguity in the use of the words "temper" and "tempering," 190.—Answers to minor criticisms in the discussion on his Paper, 191.—*Correspondence on ditto:* The whole ingot rendered available by the process of fluid compression, 201.—The American cast-steel guns, 201.—Mr. Hinsdale's experiment with small ingots, 201.—Liquid compression and plastic compression, 202.—Statements of the superiority of a particular maker's steel to be received with caution, 202.—Contraction cavities in steel, 203.—Telford medal and premium awarded to, 215, 224.

Grosclaude, J., the manufacture of slag-cement, 419.

Gun-cotton, experiments of the Italian Government on, 8.—Adoption of, for the bursting charges of shells, 8 *et seq.*

Gun, wire-, Longridge's, 53.

Guns *versus* armour, 7 *et seq.*

——, 12·6-inch, turret barbette for, on Canet's system, 462.

——, quick-firing, changes in naval warfare by the adoption of, 9 *et seq.*

Hadfield, R. A.—*Correspondence on the Treatment of Steel by Hydraulic Pressure:* Behaviour of the untreated cast-steel gun of the Standard Steel Casting Company of Thurlow, U.S., 195.—Shortening of small ingots under pressure, 195.—Dr. Müller's investigations on the gases occluded in steel, 196.—Fluid compression not of necessity requisite for the production of sound ingots, 196.

Hall, J. [illegible] *Discussion on the Treatment of Steel by Hydraulic Pressure:* Fluid compression an exploded theory, 163.—Desirability of a discussion as to the hydraulic pressure of steel after it had become solid, 164.

Hancock, W. J., elected associate member, 82.

Harbour, Libau, the extension and improvement of, 429.

Hastings, Admiral Sir T., opinion of, in regard to armour for ships, 1.

Haupt, L. M., permeability of cements and cement-mortars under pressure, 414.

Hawkshaw, J. C., elected member of council, 206, 249.

Hawksley, C., elected member of council, 206, 249.

Hay, Admiral Sir J. D., opinion of, as to a reduction of armour in ships of war, 7.—*Correspondence on Armour for Ships:* Reasons which led Sir Henry Chads in 1850 to report against iron as a material of construction, 75.—The Iron Armour-Plate Committee of 1861–64, 75.—Scepticism of sailors in respect of the alleged advantages of low freeboard, 76.—Question of armour, 76.—Policy of Great Britain in former naval wars, 77.—The new Admiralty programme, 78.

Hayter, H., elected vice president, 206, 249.

Head, J.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* Causes of the presence of gases in steel, 176.—Forging preferable to hammering for solid ingots, 176.—The Mannesmann process of rolling, 177.

Heat-expenditure in steam-engines. "*Investigation of the Heat-Expenditure in Steam-Engines, especially with reference to Methods of Diminishing Cylinder-condensation,*" Professor V. A. E. Dwelshauvers Dery (S), 254.

Henzell, C. G., elected associate member, 82.

Hewson, G., elected associate member, 204.

High explosives, experiments of naval authorities with, 8 *et seq.*

Hill, A., elected associate member, 82.

Hinsdale, —, of the Jersey City steel-works, U.S., experiments of, on the compression of small steel ingots, 195, 201.

Hirn, G. A., steam-engine, experiments of, 251, 272 *et seq.*

Hodson, F. W., admitted student, 82.

Hollingrake, J., specification of, of 1819, for casting metals under pressure, 169.

Hoops, steel, fluid compression of. See Steel.

Hopkinson, F. T., elected associate member, 82.

Howard, Vice-Admiral E. H.—*Discussion on Armour for Ships:* Advantages of four small vessels having independent points of attack over one large one costing the same money, 34.

———, T., his general scheme of 1864 for the improvement of the river Avon below Bristol, 282 *et seq.*

Howe, H. M.—*Correspondence on the Treatment of Steel by Hydraulic Pressure:* Distinction between liquid compression and plastic compression, 196.—Question of unsoundness of ignots distinct from that of quality of the steel, 197.—Whitworth compressed steel no better than the unpressed product of many other makers, 199.

Huss, L., the renewal and reconstruction of iron bridges in Austria, 422.—The Moldau viaduct at Cervena, 426.

Hydraulic pressure applied to the manufacture of steel, 83 *et seq.*

Hydrogen gas in steel, 173 *et seq.*

Induction, a general law of, in a circuit devoid of resistance, 485.

——— and leakage between neighbouring telephone wires, the suppression in a special instance of the difficulties from, 490.

Ingots, steel, fluid compression of. See Steel.

Insulators, porcelain, measurements of the insulation of, 490.

Iron Armour Plate Committee, 1861–64, history and proceedings of the, 65 *et seq.*
—— bridges. See Bridges.
—— -ore, magnetic, mountains of North Sweden and the Ural, 472.
—— -work, strains in, an apparatus for the measurement of, 428.
Isherwood, B. F., an exposition of the mode in which water is affected by a body moving in it, 463.

Jessop, W., floating dock at Bristol designed by, in 1809, 281.
Jones, —, of the Edgar Thompson steel-works, U.S., his proposal to compress steel ingots by the direct pressure of steam, 91.
——, R. J., elected associate member, 204.
Joyce, S., jun., Miller prize awarded to, 216, 225.

Kapp, G., Telford medal and premium awarded to, 215, 224.
Katte, W., elected member, 82.
Kennedy, A. B. W., testing-machine of, 315, 317.
——, N., Telford premium awarded to, 215, 225.
Kiddle, Staff-Commander W. W., memoir of, 405.
Kindermann, —, water and its cost, 439.
King-Salter, J. J., Miller prize awarded to, 216, 225.
Kolokoltzoff, Admiral J. R. N., process carried out by, at the Abouchoff Steel and Ordnance Works, St. Petersburg, for the fluid compression of steel, 84 *et seq.*—*Correspondence on the Treatment of Steel by Hydraulic Pressure:* No cavity ever found in the extreme top of the compressed ingot, 199.—From one-third to one-half the available power of the presses sufficient for practical purposes, 199.
"König Wilhelm," German armour-clad, foundering of the, 71.
Koyl's parabolic semaphore, 460.
Krüger, B., the physical action of precipitants upon micro-organisms present in water, 443.

Lake, W. G. W., elected associate member, 82.
Lanyon, Sir C., memoir of, 391.
Larroque, F., a new system of examination for iron bridges, 427.
Laurens, F., admitted student, 204.
Le Chatelier, A., the influence of temperature on the mechanical properties of metals, 413.
Le Mesurier, H. P., memoir of, 393.
Leather, S. P., memoir of, 403.
Leslie, Sir B., K.C.I.E., elected member of council, 206, 249.
——, F., memoir of, 397.
——, H. H., memoir of, 398.
Library and library-fund, list of donors to the, 235.
Lindesay, C. de la P. C., elected associate member, 82.
Line-wire for constant-current circuits, economical size of, 489.
Lippmann, G., a general law of induction in a circuit devoid of resistance, 485.
Liversidge, J. G., R.N., admitted student, 204.
Lockhart, W. S., transferred member, 82.
Locomotives, balanced slide-valves for, 369.
Longridge, J. A., wire-gun of, 53.
Lopes, G., B.A., Telford premium awarded to, 215. 225.
"Lord Warden," H.M.S., 69.
Lyster, G. F., elected member of council, 206, 249.

McDonnell, A.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* Subsequent treatment of steel by forging, 171.—Improper use of the terms "temper" and "tempering," 172.
McKerrow, A., vote of thanks to, as one of the auditors of accounts for 1889, 206. —Appointed auditor for 1890, 206.
McKie, E. P., admitted student, 82.
MacLellan, W. T., elected associate member, 204.
Magnetic-iron-ore mountains of North Sweden and the Ural, 472.
Manico's slide-valves, used on the North London railway, 370.
Manlove, Alliott & Co., apparatus made by, for testing the speed-variations of engines, 358.
Mannesmann process, the, for rolling tubes, 176.
Manning, G. W. J. E., admitted student, 82.
Mansergh, J., elected member of council, 206, 249.
Marchbanks, J., elected associate member, 204.
"**Marengo,**" French armour-clad, 5.
Marshall, J. G., elected associate member, 82.
Martell, B.—*Discussion on Armour for Ships:* Injustice to armour-plate manufacturers of the invidious mention of the results obtained with a single maker's plates, 50.
Massin, E., the suppression in a special instance of the difficulties from induction and leakage between neighbouring telephone wires, 490.
Mathieu, H., the consumption of railway sleepers in France, 454.
Matthews, W., transferred member, 82.
May, J., admitted student, 204.
Metallurgical processes, electro-, the consumption of energy in, 492.
Metals, permeability of, when hot, to gases, fluids, and solids, 179 *et seq.*
———, tensile-tests of, note on, 412.
———, the influence of temperature on the mechanical properties of, 413.
Michel, J., the new rail of the Paris, Lyons and Mediterranean railway, 457.
Micro-organisms in suspension in the atmosphere, the influence of ventilation on the, 442.
——————— present in water, the physical action of precipitants upon, 443.
Miller scholarship and prizes, award of, 225.
Mine-gas. See Gas.
—— (gold), the Arroyo Seco Gravel, 474.
Mines, tin, Maliwan (Mergui district), 468.
——, ventilation of. Experiments on the removal of mine-gas by exhaustion, 464.
"**Minotaur,**" H.M.S., 69.
Minutes of proceedings referred to in the report of the council, 214.
Moline, L. P., elected associate member, 204.
Morgan, C. L., transferred member, 82.
Morris, D., transferred member, 204.
Mortars, cement-, and cements, permeability of, under pressure, 414.
Müller, Dr. C. G., researches of, on the gases occluded in steel ingots, 85.
Musgrave, H. A. F., admitted student, 204.

Napoleon III and the introduction of armour for ships, 3 *et seq.*
Naval Construction and Armaments Company, designs of war-ships for the British Navy prepared by, 14 *et seq.*
Navy, British, armour for ships of the, 1 *et seq.*

Navy, British. "*On the New Programme for Ship-building,*" W. H. White (S.) 375.

——, French, phases of armour in the, 4 *et seq.*

Nicolaieff, port of. See Port.

Noetlong, F., report on the oil-fields of Twingoung and Beme, Burma, 469.

Nordenfelt, T.—*Discussion on Armour for Ships:* Influence of cost on the question of big *versus* little ships, 58.—The big Italian ships, 58.—Quick-firing guns, 59.—Shells charged with high explosives, 60.—Influence of "responsibility" on the question of big *versus* little ships, 61.

O'Callaghan, Major D.—*Correspondence on Armour for Ships:* Experience derived from armour-plate experiments at Shoeburyness, 78.—Delayed-action fuze for high explosives, 79.

Oelwein, A., basic steel and the canalization of the Moselle, 483.

Officers of the Institution 1889–90, list of, 249.

Oil-fields of Twingoung and Beme, Burma, report on the, 469.

Oldfield, D., elected associate member, 204.

Ordnance Select Committee, recommendations of the, as to a riband-gun, 53.

Oriolle's shallow-draught screw-steamer, 461.

Outridge's slide-valves used on the North London Railway, 370.

Palaz, A., the Dessendier recording-photometer, 449.

Papers (original communications), subjects for session 1889–90, 226.—Ditto received between April 1, 1888, and March 31, 1889, 231.

Parabolic Semaphore. See Semaphore.

Park, D., balanced slide-valve of, used on the North London Railway, 370.

——, J. C., "*Balanced Slide-Valves*" (S.), 369.

Parker, W.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* Suitability of the Whitworth compressed steel for marine-engine shafts, 146.—Proper treatment of the ingot for producing steel-plates, 147.—Opinion of Mr. Pourcel and Mr. Barba that homogeneous ingots could be produced by chemical treatment, 147.—Tests of forged- and cast-steel and wrought-iron to withstand tension, torsion, and bending, 149.—Uncertainty existing as to the value or otherwise of putting a large amount of work into steel, 150.

Parkin, J. H., elected associate member, 82.

Paving-setts, the peculiarities in the wear of, 433.

Pearce, R., the smelting of gold and silver ore at Argo, Colorado, 477.

Percival, H. S., admitted student, 204.

Perkins, L., his high-pressure system for marine boilers, 52.

Petri, Dr. R. J., the employment of carbonic-acid gas for the determination of the air-renewal in inclosed spaces, 445.

Photometer-recording, the Dessendier, 449.

Pictures in the possession of the Institution, referred to in the report of the council, 219.—List of, 248.

Pole, Dr. W.—*Discussion on Armour for Ships:* History of armour-plating for ships, 63.—Proceedings of the Government "Iron Armour-Plate Committee" of 1861–64, 65.—Vote of thanks to, as honorary secretary, 206.

Ponthière, H., the consumption of energy in electro-metallurgical processes, 492.

Pontifex, E. A., transferred member, 82.

Port of Nicolaieff, the, 430.

Pourcel, —, his process of steel-making at Terre Noire, 147.

Precipitants, the physical action of, upon micro-organisms present in water, 443.

Preece, W. H., elected member of council, 206, 249.

Premiums awarded, session 1888–89, 224.

Press, hydraulic, for the compression of fluid steel, 83, 95 *et seq.*

Preston, A. E., transferred member, 204.

Puddling in gas-furnaces, the development and present condition of, 480.

Pullen, W. W. F., Wh.Sc., Telford premium awarded to, 216, 225.

Pump, wave-power, 434.

Pumping-engines, duty-trials of, 434.

Rail, the new, of the Paris, Lyons and Mediterranean Railway, 457.

Rails, steel, on the duration of, 456.

Railway, Caledonian, type of bogie used on the, 301.

———, Canadian Pacific, form of truck in use on the, for cars, 296.

———, Ciaño-Santa Ana to Soto del Rey, 450.

———, Grand Trunk, form of balanced slide-valve used on the, 371.

———, Great Northern, simple form of bogie used on the express engines of the, 300.

———, Great Southern and Western, swing-bar used on the, 300.

———, Kaiping-Tientsin, the, in China, 452.

———, London and South-Western, Adams' bogie on the, 301.

———, North-Eastern, bogie for compound express engines on the, 302.

———, North London, forms of balanced slide-valves used on the, 369.

———, Paris, Lyons and Mediterranean, the new rail of the, 457.

———, Pennsylvania, car-truck in use on the, 297, 299.

———, Pyrenean. Projected international railway through the centre of the Pyrenean range, 453.

———, Taff Vale, Mr. Hurry Riches' bogie on the, 297.

———, Thylands, Denmark, form of bogie used in the, 302.

———, Zafra to Huelva, 453.

———-rolling stock. See Rolling-stock.

——— signals. Koyl's parabolic semaphore, 460.

———-sleepers, consumption of, in France, 454.

Ransom, H. B.—Miller prize awarded to, 216, 225.—"*The Cyclical Velocity-Variations of Steam and other Engines*" (S.), 357.

Rates, local, assessment of the Institution to, referred to in the report of the council, 218.

Rawlinson, Sir R., K.C.B.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* His idea, reasoning from the method employed for expelling air from china-clay, that hydraulic pressure of the gases in steel would simply compress them into smaller volumes, 164.—Elected vice president, 206, 249.

"**Re Umberto**," Italian war-ship, 58.

Reade, Capt., R.N., lecture on war-ships, 74.

Reed, Sir E. J., K.C.B., M.P.—*Discussion on Armour for Ships:* Meaning of Sir N. Barnaby's term, "phases of armour," 25.—The French ships "Dupuy de Lôme" and "Tage," 26.—Relative importance of power to inflict damage and power to resist it, 28.—Different aspects of the question regarded from the point of view of the sailor and of the taxpayer, 28.—Vital importance of keeping the invader out of England, 30.—Unsatisfactory nature of the present proposals for increasing the Navy, 31.—His preference for numbers if the ships to be built were not absolutely invulnerable, 31.—Mr. George Rendel and the Admiralty, 32.—Advisability of competent criticism on the present Admiralty designs, 33.—Elected member of council, 206, 249.

Rendel, G W., his connection with the Admiralty referred to, 22, 32.

Report of the council, session 1888-89, 207.—Constitution of the Institution, 207.—Composition of the council, 209.—The president, 211.—Roll of the Institution, 212.—Admission of students, 213.—Minutes of proceedings, 214.—Ordinary meetings, 215.—Students' meetings and visits to works, 215.—Crampton prize, 216.—Finance, 217.—Assessment for local rates, 218.—Westminster (Parliament Street, &c.) Improvement Act, 218.—Menai suspension bridge, 219.—Pictures, 219.—Abstract of receipts and expenditure from the 1st April, 1888, to the 31st March, 1889, 220.—Premiums awarded, session 1888-89, 224.—Subjects for papers, session 1889-90, 226.—Original communications received between Aprli 1, 1888, and March 31, 1889, 231.—List of donors to the Library and to the Library Fund, from April 1, 1888, to March 31, 1889, 235.—List of paintings in the possession of the Institution, 228.—List of officers, 1889-90, 249.

Reynolds, E.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* Process of compressing fluid metals obsolete and valueless, 168.—Patent of James Hollingrake of 1819, 169.—The only way to obtain good steel is to make it properly and leave it alone, 169.—Theory of "dead-melting," 170.

Rhodes, —, economical size of line-wire for constant-current circuits, 489.

Riches, H., form of bogie adopted by, for the Taff Vale Railway, 297.

Rigby, A. B., admitted student, 82.

Riley, J., his Paper on the treatment of steel read before the Iron and Steel Institute, 150.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* The experiments which led him to form the views enunciated in his Paper before the Iron and Steel Institute, 151.

River Avon. "*The Improvement of the River Avon below Bristol,*" W. Chatham (S.), 280.—Condition of the river until 1809, 280.—Floating dock designed by William Jessop, 281.—Dock-improvement by I. K. Brunel in 1848, 281.—Thomas Howard's general scheme of improvement of 1864 for the lower river, 282.—Execution of the modified scheme, 283.—Blasting rock, 285.—Plant employed, 287.—*Appendix:* Details of cost of work at Round Point, 1883-85, 291.

———, Bilbao, progress of the works of improvement in the, 433.

——— Moselle. Basic steel and the canalization of the Moselle, 483.

Roads, the peculiarities in the wear of paving-setts, 433.

Robbins, E.—*Discussion on Armour for Ships:* New mode of construction suggested for ships of war, 52.

Roberts-Austen, W. C.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* Period at which the occluded gases are supposed to be eliminated, 157.—Ambiguity in the ordinary use by engineers of the terms "temper" and "tempering" as applied to steel, 158.

Roe, J. P., memoir of, 405.

Roll of the Institution, referred to in the report of the Council, 212.

Rolling-stock.—"*Flexible Wheel-bases of Railway Rolling-stock,*" J. D. Twinberrow (S.), 292.—Flexible wheel-base universally adopted by American Engineers, 292.—General considerations of correct rolling-motion on a curve, 292.—The Bissell bogie, 296.—Form of truck used on American and Canadian railways, 296.—Taff Vale Railway bogie, 297.—Single-axle truck used in England, 297.—Standard engine-truck, Pennsylvania Railroad, 299.—Swing-bar bogie on the Great Southern and Western Railway, 300.—Stirling's bogie on the Great Northern express engines, 300.—Adams' bogie on the South-Western Railway, 301.—Caledonian Railway bogie, 301.—North-Eastern Railway bogie, 302.—Thyland's Railway bogie, 302.—Retention of long, rigid wheel-bases by English railway companies, 304.—Dimensions of American freight-cars, 306.

Rothwell, J. E., method of treating gold-ore at Deloro, Canada, 476.
Roux, G., an experimental theory of lead accumulators, 491.
Rubbish from old buildings, the utilization of, 421.
Runeberg, R., Watt medal and Telford premium awarded to, 215, 224.
Russian war of 1854–6, armoured ships used in the, 2 *et seq.*

Sacheri, G., viaduct over the Adda at Paderno, 424.
Sacré, C. R., memoir of, 399.
Schomburg, —, measurements of the insulation of porcelain insulators, 490.
Schwarz, A., the water-supply of Tôkiô, 441.—The Kaiping-Tientsin Railway in China, 452.
———, — von, magnetic-iron-ore mountains of North Sweden and the Ural, 472.
Scorgie, N., elected associate member, 204.
Scott, Rear-Admiral R. A. E.—*Correspondence on Armour for Ships:* Review of Sir N. Barnaby's proposals for small ships, 80.—Sir Thomas Hastings' opinion against iron for war-ships shared by all those who witnessed the experiments of 1850, 80.—Deficiency in the supply of guns for the British Navy, 81.
Seebohm, —, experience of, in trying to make gun-barrels of Bessemer steel, 88.
Segundo, E. C. de, the Miller scholarship awarded to, 216, 225 —"*Experiments on the Strain in the Outer Layers of Cast-Iron and Steel Beams*" (S.), 308.
Selwyn, Admiral J. H.—*Discussion on Armour for Ships:* Necessity of providing strong boilers where continuous high speed was required, 52.—Boilers of the "Wanderer" on Perkins' principle, 52.—Mr. Longridge's wire gun, 53.—Manufacture and performance of compound armour, 54.
Semaphore, parabolic, Koyl's, 460.
Shallow-draught steamer. See Steamer.
Shelford, W., elected member of council, 206, 249.
Shield, W., elected member, 82.
Ships of war, 1 *et seq.*
————, British, proposals for new types of, 11 *et seq.*—"*On the New Programme for Ship-building,*" W. H. White (S.), 375.—Admiralty scheme for seventy vessels to be completed before the 1st of April 1894, 375.—Second-class protected cruisers, 375.—First-class cruisers, 377.—Second-class battle-ships, 377.—First-class battle-ships, 379.—Comparison between the "Warrior" of 1859 and the new first-class battle-ships, 386.
Siemens, F., his Paper on the occurrence of bubbles in molten glass, 176.
Silver-ore, the melting of, at Argo, Colorado, 477.
Simpson, J., memoir of, 400.
———, W., admitted student, 82.
Slag, utilization of, 421.
——-cement, the manufacture of, 419.
Sleepers, railway, consumption of, in France, 454.
Slide-valves. "*Balanced Slide-Valves,*" J. C. Park (S.), 369.—Forms of balanced slide-valves used from time to time on the North London Railway, 369.—Thomas Adams' valves, 369.—David Park's valve, 370.—Outridge's valves, 370.—Dawe's valves, 370.—Manico's valves, 370.—Valve used on the Grand Trunk Railway of Canada, 371.
Smith, E. M., elected associate member, 82.
———, H. B., transferred member, 204.
———, J., Wh.Sc., admitted student, 204.
———, R. H., Telford premium awarded to, 215, 224.
Sosnovsky, K., experiments on the practical values of galvanic batteries, 485.

Sowerby, W.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* Piping of steel ingots, 175.—Improvement of every description of steel by working, 175.—Probable action of the molten steel under the pressure of 10,000 tons, 175.—Means of getting rid of the air and water contained in china-clay, 176.

Speed-variations. "*The Cyclical Velocity-Variations of Steam- and other Engines,*" H. B. Ransom (S.), 357.

Spencer, J. W.—*Discussion on the Treatment of Steel by Hydraulic Pressure:* Reasons for dissenting from the statement that absolutely sound cast ingots could not be made, 165.—Table of tests of specimens cut from an ingot not subjected to mechanical treatment, 166.

Squire, W. W., elected member, 82.

Standard Steel Casting Company of Thurlow, U.S., cast-steel guns of the, 195.

Steam-engine.—"*Experiments on a Steam-Engine, the Cylinder of which was heated externally by Gas-flames.*" B. Donkin, jun. (S.), 250.—Description of the engine used, 250—Summary of experiments with and without gas-flame jacket, 251.—Summary of experiments with the same engine, but condensing with and without gas-flame jacket, 252.

——— ———.—"*Investigation of the Heat-expenditure in Steam-Engines, especially with reference to Methods of Diminishing Cylinder Condensation.*" Professor V. A. E. Dwelshauvers Dery (S.), 254.—Method of calculation, 254.—Notation employed, 255.—Graphic representation of the quantities of heat, 255.—Drawing the mean diagram of exchanges, 257.—Diagram of absolute work and of absolute loss by the metal, 257.—Definition of the absolute loss of heat due to the cylinder-walls, 258.—Distinction between positive and negative quantities of heat, 258—Scales of the diagrams, 259.—Data of the engine experimented on, 260.—Mode of proceeding in studying the trials, 261.—Classification of the results, 262.—Action and economy of the gas-flame jacket, 265.—Resultant action of the sides, 267.—Means of determining the exhaust cooling when not directly measured, 268—Variation of the dryness-fraction during expansion, 269.—Results shown by the diagram, 270—Balance-sheet of the engine, 270.—Supplementary explanation, 271.—Means of increasing the efficiency, 272.—Utility of Donkin's gas-flame jacket, 273—Utility of surface-heating, 274.—Utility of high speed, 274.—Comparison of the three methods, 275.

——— ————"*The Cyclical Velocity-Variations of Steam and other Engines.*" H. B. Ransom (S), 357—Definition of cyclical velocity-variations, 357.—Description of the recording apparatus used, 358—First experiments on the steam-engine, University College, London, 360.—Gas-engine trials, 366.

Steamer, screw-, shallow-draught, 461.

Steel. "*The Treatment of Steel by Hydraulic Pressure, and the Plant employed for the purpose,*" W. H. Greenwood, 83.—Patents of Sir H. Bessemer and Sir J. Whitworth for fluid compression, 83.—Adoption of the process at the Abouchoff works, St. Petersburg, 83—Unsoundness of steel ingots, 84.—Methods employed for improving the soundness of mild steel ingots, 89.—The hydraulic press, moulds, and plant for the fluid compression of steel by hydraulic pressure, 93.—General arrangement of the plant at the Abouchoff works, 103. —Conduct of the process of fluid compression, 105.—Casting of hoops or hollow ingots, 109.—Effect and advantages of the fluid compression of steel, 110.—Comparative tests made upon pressed and unpressed cast-ingots, 120.—Conclusion, 131.—*Appendixes,* I and II. Tests from an unpressed ingot, 133. —III, IV and V. Summary of results from test-pieces cut parallel to the length of the ingot, 139—VI. Summary of average results from test-pieces cut in a plane at right-angles to the length of the ingot, 140.—VII. Mean results obtained from the test-pieces cut longitudinally and at increasing distances from the centre, 141.—VIII. Mean results obtained from the test-pieces cut transversely and at increasing distances from the centre, 143.—Details of the conduct of the fluid compression of steel ingots and hoops, 144.—*Discussion:* J. D. Ellis, 145; W. Parker, 146; J. Riley, 151; T. E. Vickers, 152; W. C. Roberts-Austen, 157; Colonel H. Dyer, 159; B. Walker, 162; J. F. Hall, 163; Sir R. Rawlinson, 164; J. H. Davis, 164; J. W. Spencer, 165; E. Reynolds, 168; T. W. Traill, 171; A. McDonnell, 171; E. A. Cowper, 172; W. Sowerby, 175; J. Head, 176; J. Goodman, 177, 180; Prof. W. C. Unwin, 179; W. Anderson, 180; Lord Armstrong, 183; W. H. Greenwood, 185.—*Correspondence:* J. O. Arnold, 193; T. Firth, 194; R. A. Hadfield, 195; H. M. Howe, 196; Admiral Kolokoltzoff, 199; B. H. Thwaite, 199; W. H. Greenwood, 201.

Steel, basic, and the canalization of the Moselle, 483.

—— beams. See Beams.

—— rails. See Rails.

Steele, A. C. D, admitted student, 82.

Stephenson, George, medals, award of, 214, 224.

Stern, Dr. R., the influence of ventilation on the micro-organisms in suspension in the atmosphere, 442.

Stileman, F. C., remarks of Sir G. B. Bruce, president, as to the death of, 203.—Memoir of, 401.

Stirling's bogie on the Great Northern Railway, 300.

Strains in ironwork, an apparatus for the measurement of, 428.

Students of the Institution referred to in the report of the council, 213.—Students' meetings and visits to works, 215.—The Miller scholarship and Miller prizes awarded to, 225.

Swiney, J. H. H., B.A., B.E., elected associate member, 204.

"Tage," French armour-clad, 5 *et seq.*

Taylor, T. G., admitted student, 82.

———, W. J., elected associate member, 82.

Teasdel, J. E., joint-engineer for underpinning Great Yarmouth Town Hall, 372.

Telephone wires, neighbouring, the suppression in a special instance of the difficulties from induction and leakage between, 490.

Telford, Watt, George Stephenson medals, Telford premiums, and the Miller scholarship and Miller prizes, award of, 214, 229.

Temper and tempering, alleged ambiguity of the terms, as applied by steelmakers, 158, 172, 190.

Temperature, the influence of, on the mechanical properties of metals, 413.

Testing-machines used in Mr. Segundo's experiments on beams, 338.

Tests, tensile, of metals, note on, 412.

Thies, A., barrel chlorination, 484.

Thomas, B., admitted student, 82.

———, W., elected associate member, 82.

Thomson, G. H., elected member, 82.

————, Sir W., elected honorary member, 204.

Thwaite, B. H.—*Correspondence on the Treatment of Steel by Hydraulic Pressure:* Behaviour of the liquid ingot in the mould, 199.

Tin-mines. See Mines.

Tôkiô water-supply. See Water-supply.

Tomkins, W. S., elected member, 82.

Touchard, Admiral, French Navy, reasons of, for advocating a reduction in armour for ships, 6, 76.

Tovey, Col. H., R.E., memoir of, 408.

Town Hall. "*Underpinning Great Yarmouth Town Hall,*" F. E. Duckham (S.), 372.

Traill, J. C., B.A., admitted student, 204.

———, T. W., tests of steel made for, 166.—***Discussion on the Treatment of Steel by Hydraulic Pressure:*** The adoption or non-adoption of fluid compression a commercial question, 171.—Invariable excellence of the specimens of fluid-pressed steel tested by him, 171.

Tramways of Madrid, the, 461.

Twinberrow, J. D., Miller prize awarded to, 216, 235.—"*Flexible Wheel-bases of Railway Rolling-stock.*" (S.), 292.

"*Underpinning Great Yarmouth Town Hall,*" F. E. Duckham (S.), 372.

Unwin, Professor W. C.—***Discussion on the Treatment of Steel by Hydraulic Pressure:*** Desirability of determining exactly the condition under which tests of materials should be conducted, 179.—Mr. Goodman's autographic diagram of steel tested hot, 180.—Difficulty of maintaining a uniform temperature of the air-bath, 180.

Ventilation, the influence of, on the micro-organisms in suspension in the atmosphere, 442.

——— ——— of mines, experiments on the removal of mine-gas by exhaustion, 464.

Vernon-Harcourt, L. F., Telford premium awarded to, 215, 225.

Viaduct over the Adda at Paderno, 424.

————, Cervena, the, over the Moldau, 426.

Vickers, T. E., steel armour-plates manufactured by, 50 *et seq.*—***Discussion on Armour for Ships:*** Material of which armour-plates should be made, 61.—Performance of two steel plates recently tested by the Admiralty, 61.—***Discussion on the Treatment of Steel by Hydraulic Pressure*****:** His reasons for dissenting from the statements put forward as to the benefits of the Whitworth compression process, 152.—Specimen ingots cast to prove the non-existence of a zone of unsoundness in proper material, 153—Early solidification of the outer surface of the molten ingot acting to prevent the expulsion of occluded gases, 155.—Alleged acicular structure of steel ingots cooled without pressure, 155.—Discussion of Mr. Greenwood's test of a compressed ingot, 156.

Walker, B.—***Discussion on the Treatment of Steel by Hydraulic Pressure:*** The alleged unsoundness of ordinary steel ingots greatly exaggerated, 162.—Various methods of treating steel ingots so as to get the bad material into the head, 163.—Ambiguity in rating the power of hydraulic forging-presses, 163.

————, G. B., elected associate member, 82.

"Wanderer," s.s., boilers of the, on Perkins's high-pressure system, 52.

Ward, E. T., elected associate member, 82.

"Warrior," H.M.S., construction of, 65 *et seq.*

War-ships. "*Armour for Ships,*" Sir N. Barnaby, 1.—"*On the New Programme for Ship-building,*" W. H. White (S.), 375.

Waste products, the utilization of, 421.

Water and its cost, 439.

———, micro-organisms present in, the physical action of precipitants on the, 443.

Water-supply of Tôkiô, 441.

——— ——— of Wiener-Neustadt, 440.

———, an exposition of the mode in which water is affected by a body moving in it, 403.

Watt medals, award of, 214, 224.

Waud, E. V., admitted student, 204.

Wave-power pump, 434.

Webb, F. W., his centrifugal process for casting steel, 91.—His opinion that to obtain a sound plate it should be worked from an ingot quite twenty times its thickness, 147.—Elected member of council, 206, 249.—Form of radial axle-box adopted by, 299.

Westinghouse brake. See Brake.

Westminster (Parliament Street, &c.) Improvement Act referred to in the report of the council, 218.

Wheels, flangeless, the use of, in the middle of six-wheel trucks, 458.

White, R., appointed one of the auditors of accounts for 1890, 206.

———, W. H.—*Discussion on Armour for Ships:* Sir N. Barnaby's historical phases of armour, 40.—French war-ship "Brennus," 40.—Necessity of regarding the distinction between small battle-ships and large cruisers, 41.—Admiralty programme of 1889 for new ships for the British Navy, 41.—The new cruisers "Blake" and "Blenheim," 46.—Manufacture of armour, 47.—Fine quality of the plates recently made at Sheffield, 47.—Conditions of the recent Admiralty test of special armour-plates, 51.—"*On the New Programme for Ship-building.*" (S.), 375.

Whitworth, Sir J., his process for the fluid compression of steel, 83 *et seq.*—His Paper read before the Institution of Mechanical Engineers in July 1875, 169.

——— ——— and Co., designs of new war-ships for the British Navy proposed by, 14 *et seq.*

Wiener-Neustadt water-supply. See Water-supply.

Willans, P. W., steam-engine experiments of, 251 *et seq.*

Williams, E., elected associate member, 82.

———, H. M., elected associate member, 82.

Willis, W., elected associate member, 82.

Wilson, A., his mode of manufacturing compound-armour as carried out by Messrs. Cammell and Co, Sheffield, 15.

Wood, A. P., elected associate member, 204.

Woodite as a material for protecting ships of war, 13, 33 *et seq.*

Woodside, J., elected associate member, 204.

Woodward, H. R. K., admitted student, 204.

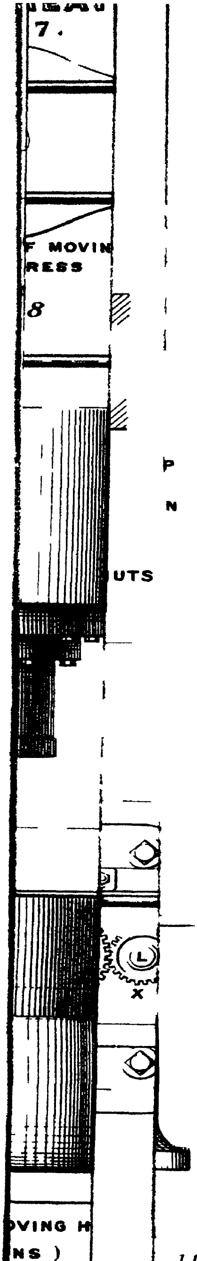
Worsdell, T. W., form of radial axle-box adopted on the North-Eastern Railway, 297.

Worthington, E., Telford medal and premium awarded to, 215, 224.

Yarmouth town hall. See Town Hall.

Young, R. G., elected associate member, 204.

LONDON: PRINTED BY WM. CLOWES AND SONS, LIMITED, STAMFORD STREET
AND CHARING CROSS.



OVING H

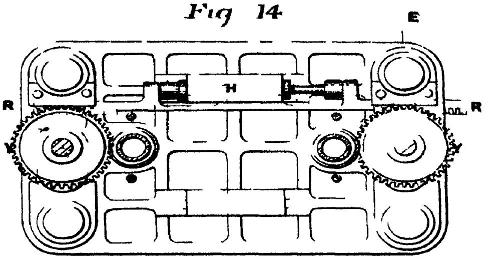
NS)

E S S

1 f 1 15 20 Feet

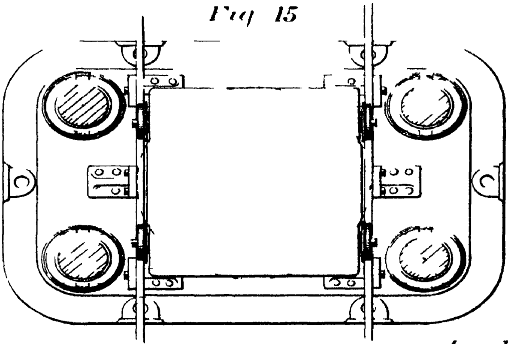
Proceed

Fig 14



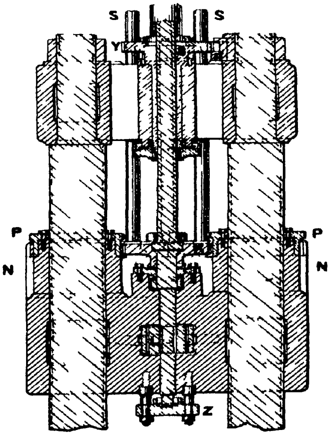
PLAN OF FIXED HEAD ON LINE A B., Fig 1

Fig 15



PLAN OF BASE ON LINE C D, Fig 12

Fig 16



TRANSVERSE VERTICAL SECTION ON LINE E F, Fig

TH KFIL & N LITH 40 KIN ST VF I I ARI I N

EXPE

N J

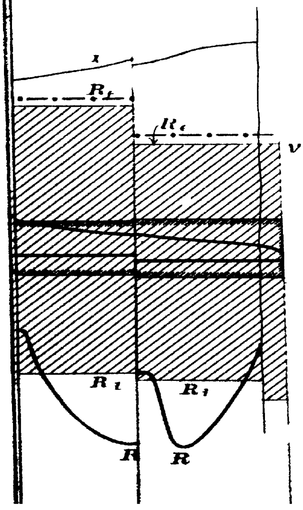
PLATE 2

XPE

16.

III

D e ıl a I'
Sp I IIŁ > s
I r pr s Sıc DI D3



III

D I
Sı I I S)
I I I I) II

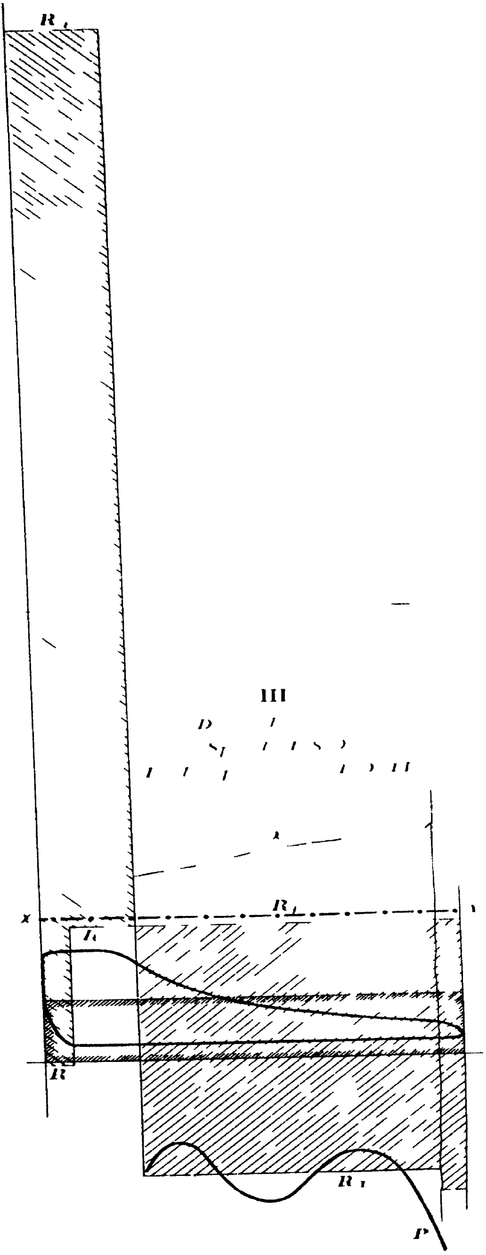
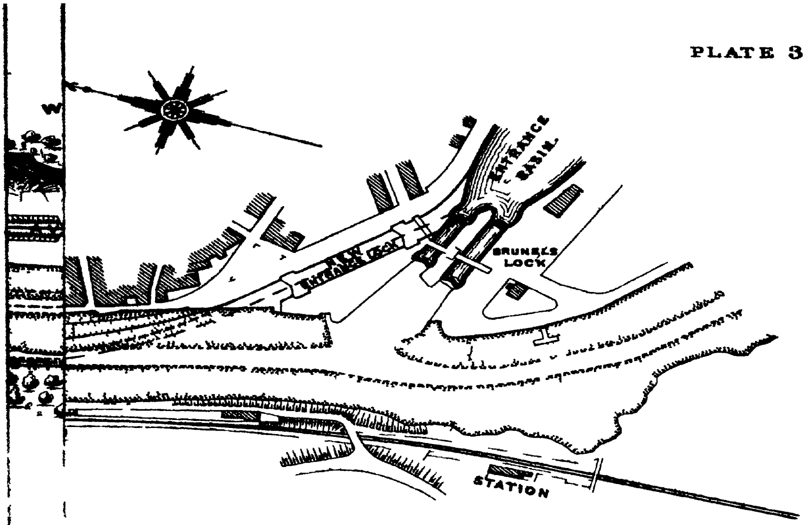
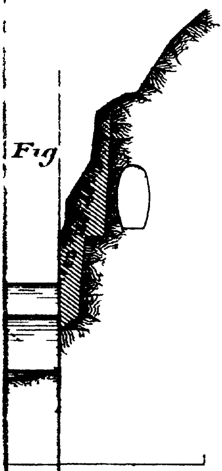


PLATE 3

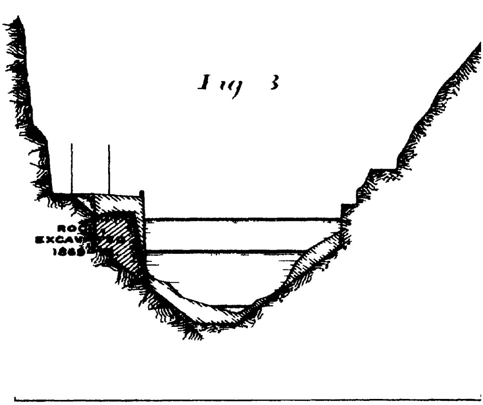




-AN POINT

r Eng' 200

Scale 40



SECTION AT HOTWELL HOUSE POINT

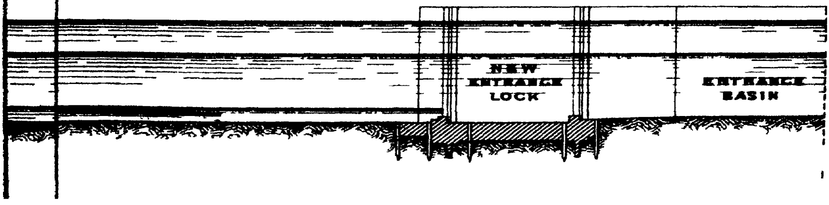
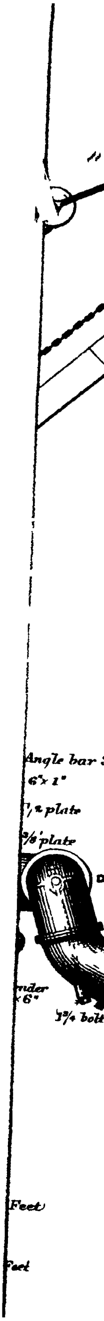


PLATE . 4 .



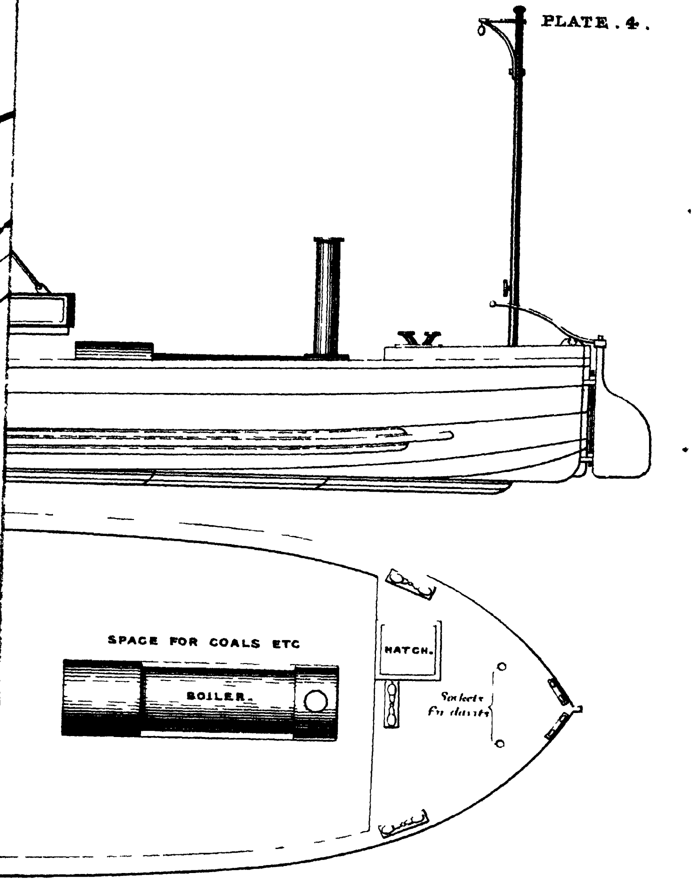


Fig 12.

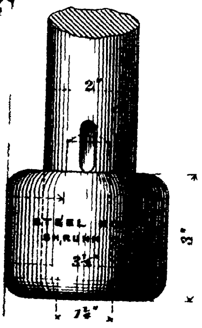
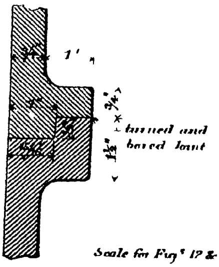


Fig 13.



Scale for Figs 12 & 13 ¼ full size

SWIVELLING JOINT

Fig 1

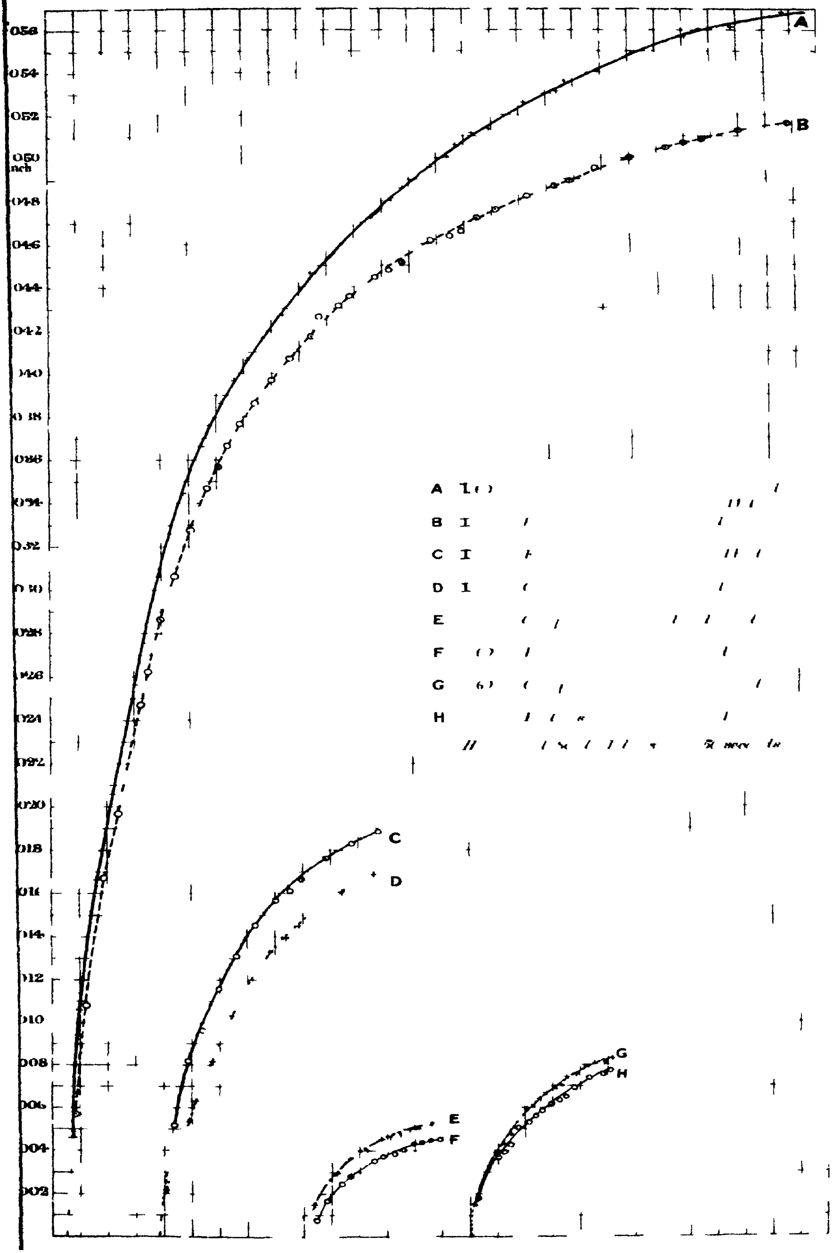

·056
·054
·052
·050
inch
·048
·046
·044
·042
·040
·038
·036
·034
·032
·030
·028
·026
·024
·022
·020
·018
·016
·014
·012
·010
·008
·006
·004
·002
A
B
C
D
E
F
G
H

PLATE 7

Fig

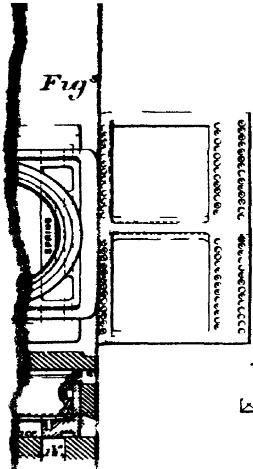


Fig 10

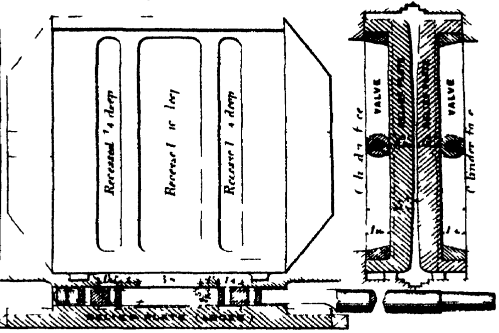


Fig 11

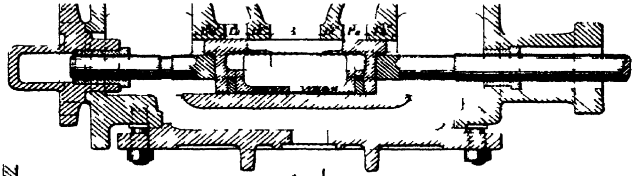
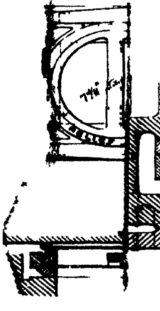
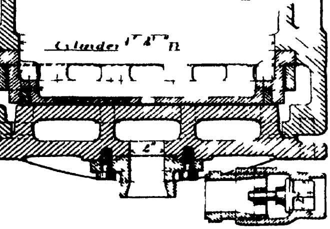
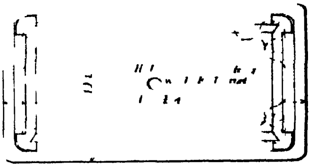


Fig 4





AIR-VALVE



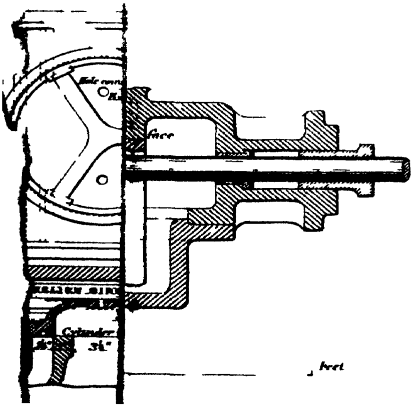


Fig 9

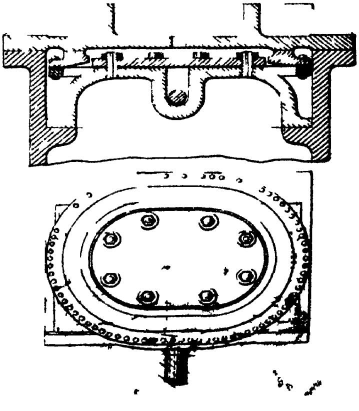


PLATE 8.

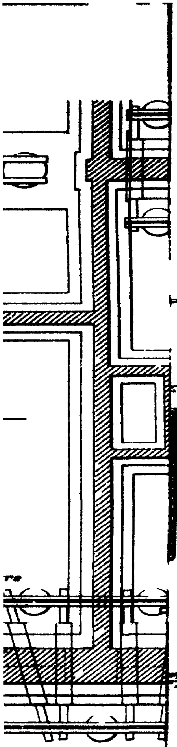
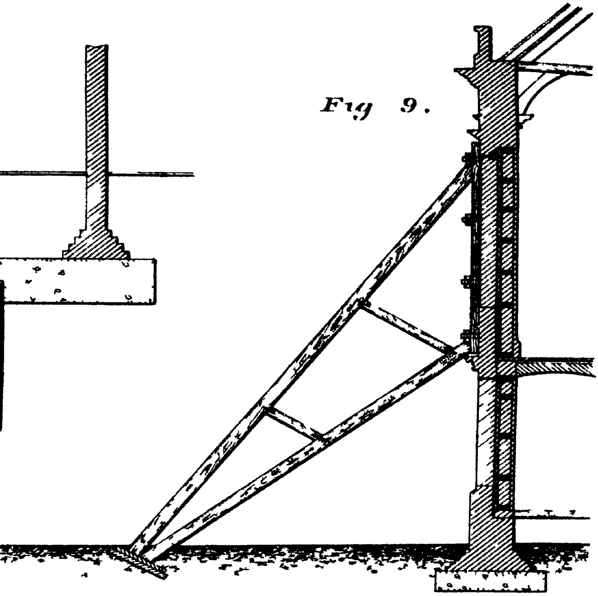


Fig 4

Fig 9.



RAKING SHORE

Scale 1/16 inch = 1 foot

Fig 8